

Cranio-maxillofacial Buttresses

Anatomy and Operative Repair

Richard A. Pollock



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To
MATHEW HENRY CRYER, MD, DDS
(1840–1921)
and
REED OTHELBERT DINGMAN, MD, DDS
(1906–1985)

“It is widely accepted that the Balsam which naturally lies in bone heals fractures; the Balsam which naturally lies in the flesh heals flesh. It is also understood that each and every part carries its own power of healing so that Nature, with this inherent ability, will heal wounds. Thus shall every surgeon know that it is not he that heals but it is the Balsam in the body which heals.”

–Theophrastus Bombatus von Hohenheim
aka Paracelsus, *Opus Chirurgicum*,
1565

“[In preexisting structures, there] were three tunnels, a tall one flanked by two smaller ones in a head-and-shoulders shape, forming a nave with side aisles. The side walls of the central tunnel were reduced to two lines of pillars linked by arches, forming an arcade . . . Masons [in doing so] relied on thick walls for strength, [in which they] nervously inserted mean little windows that let in hardly any light.”

“But a cathedral had to be a dramatic building, awe-inspiring in its size, pulling the eye heavenward with its loftiness . . . The weight of lead and timber in the roof would be too much for the walls . . . [were they not] propped up by . . . archways, extra supports at intervals in the roof space of the side aisles, . . . [each] braced further with a massive buttress jutting out from the side . . . with a turret on top, to add weight and make it look nicer.”

“The foundations, far underground beneath the walls, . . . [aided the cause, allowing great height and size]. Laymen were always surprised at how deep . . . [they] were.”

“[Further, there is nothing] wrong with the idea of naked buttressing . . . a line of sturdy, stone columns . . ., strengthening members in a position where they would be starkly visible, . . . [each] with a pinnacle on top and each propping up remotely the walls, at a distance.”

–Tom Builder
Ken Follett, *Pillars of the Earth*
(New York: New American Library (Penguin Group); 2002)

“The fine bones of her lovely face took on a spare, almost structural beauty . . . like . . . my flying buttresses.”

–Jack Jackson
Ken Follett, *Pillars of the Earth*
(New York: New American Library (Penguin Group); 2002)

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Foreword

Dr. Pollock and his contributors have met their goals and gone beyond: “This text is intended as an educational tool for the neophyte and the sophisticate, but, by design, has an emphasis on surgical anatomy that would form a basis for surgical intervention.” Although the focus is on the buttresses of the cranium and face, including the microbuttresses of the orbit and periorbit, all craniomaxillofacial fractures and dislocations are described in helpful detail, accompanied by lavish illustrations that are on the same page as the text. No helter-skelter shuffling; everything in this book has been done with exquisite attention to teaching. Dr. Pollock has provided instructive algorithms that are not specific just to interruption of the craniofacial skeleton but rather are directed toward the patient and doing what is the most important: first establish an airway, manage hemorrhage, identify and document the clinical issues, and consult with other colleagues, when appropriate. The author reminds us that the injured patient can die from general mismanagement, less often from an unrepaired facial fracture.

I confess that when I was trained and was first in practice (1963) and for many years afterward, plating for maxillofacial fractures was not in vogue. Treatment consisted generally of realigning fragments, using wires and, when needed, interdental fixation with arch bars.

Dr. Pollock presents the concept of buttresses as a fascinating, historical chronicle, beginning with sanctuaries of worship, such as Notre Dame in Paris and Westminster Abbey in London. What

has taken us human beings a few thousand years to understand, nature through evolution has known for millions of years. *The human face is our sanctuary, and it does have buttresses, which protect, maintain balance, and offload heavy forces.*

He and his contributors discuss the physics and biomechanics of craniofacial buttresses in understandable prose. The text is gracefully written; every word has been chosen carefully. Seldom is a reader fortunate to find and learn from a book so much, so effortlessly.

The author warns appropriately: “Many maneuvers and details of operative repair should be garnered by further reading and experience.” This remarkable book is an indispensable launching pad.

—Robert M. Goldwyn, MD
Brookline, Massachusetts
25 March 2009*

*Robert M. Goldwyn died 23 March 2010. Like M. Henry Cryer, MD, DDS, at the turn of the 20th century, to whom this book is dedicated, Dr. Goldwyn recognized profound parallels between sanctuaries of worship and the craniofacial skeleton (with its buttresses, “flying buttresses,” “microstruts,” “platforms,” “floors,” and “walls”). Before he died, Dr. Goldwyn read the manuscript of *Craniomaxillofacial Buttresses*, as it was then written, and advised it begin with a discussion of these sanctuary-skeletal parallels. The discussion was duly added, as Part 1 of Chapter 1, before he penned this Foreword.

Foreword

This work represents an enormous accumulation of historical research and clinical data whose thesis is a description of the bony components of the craniofacial skeleton. It begins with an acknowledgment of the historical descriptions of the human craniomaxillofacial skeleton and their corollaries in architecture. The physiology described in the subsequent chapters includes a discussion of structural physics, load-bearing capacity, basic biomechanics, and implications of finite analysis. The text, in exquisite and well-referenced detail, then traverses the evolution of general principles of craniomaxillofacial buttress reconstruction and their application in the last half of the 20th century and first decade of the 21st century in facial trauma repair.

These principles are serially studied with regard to each anatomical section of the face and accompanied by detailed discussion, all profusely referenced and liberally illustrated by anatomical and clinical examples. Indeed, this book studies the detail of each anatomical region of the craniofacial skeleton, from the mandible and palatal platform, to the cranial base and adjacent vaults.

Craniomaxillofacial Buttresses is characterized by the detailed, wonderfully illuminating artwork of William Winn. Profuse “exemplary” repairs are drawn from the author’s extensive personal experience. Combined, the art and clinical cases help the reader understand the relationship of anatomy to the principles of surgical reconstruction and perceive absolutely the appropriate difficulty of obtaining superior results.

There are no facial fracture texts in any of the five specialties that deal with facial injury in this amount of detail, nor do they cover all of the craniofacial areas of modern interest, as does this text. Classically, each specialty places emphasis on certain, select areas. This text is highly original and focused, yet thoroughly demonstrates competence in all areas of craniofacial reconstruction. In doing so, it draws on the expertise of all five participating specialists.

The extensive literature mentioned and summarized in the text is itself worth the purchase price of the book, were that its only value. The task of collecting this information is truly so large. *A collection of this type, with this subject as focus, has not occurred in the facial fracture or craniomaxillofacial surgery literature in the past 70 years.*

This book serves as a tribute to the many individuals, who through their individual labors have sought to make operative sense of the complexity of the bony skeleton of the cranium, face, and their related soft tissues. The text brings together history, clinically applied anatomy, and surgical technique in a way that has not been accomplished previously for the buttresses of the craniofacial skeleton.

As much of my life has been spent trying to develop algorithms for the efficient and successful reconstruction of the face following injury and tumor removal, I am personally keenly aware of what this volume represents in terms of work, effort, and surgical experience. How different it would have been to have such a text available to me in the past! But it is here now! In this current, first edition and in future editions, *Craniomaxillofacial Buttresses* will enrich a generation of young surgeons enthusiastic about discovering their heritage and ardent in pursuing the intricate anatomical principles and techniques that lead to exemplary results in clinical surgery.

My thanks and appreciation to Richard A. Pollock, whose energy and dedication has made such an encyclopedic text available as a reality.

—Paul N. Manson, MD
Professor and Chief, Plastic Surgery
Johns Hopkins Hospital and
The University of Maryland Shock Trauma Unit
Baltimore, Maryland

Foreword

Craniomaxillofacial Buttresses is a masterful work, of which Dr. Pollock, his contributors, and those of us active in the field of clinical anatomy can be proud. Pollock first acknowledges the giants—architects, anatomists, and surgeons—upon whose shoulders we stand. Building upon this historical context, the structural components of the craniofacial skeleton are analyzed, recognizing that buttresses provide the biomechanical basis of mastication, speech, facial appearance, and identity, even the alignments and support necessary for vision and respiration. Operative techniques and the rationale for restoration are supported by examples of judicious, clinical repair.

In this text, structural and functional anatomy are applied in the context of patient care, making it an excellent presentation of *clinically applied anatomy*. Not limiting their work to analyses of structure and the structural basis of craniofacial function, the author and his contributors consider the functional consequence of traumatic loss, thus setting the stage for lessons in clinical diagnosis and restoration.

This treatise is an epitome of applied clinical anatomy, a subject of great interest to me and my colleagues. As a Founding Member and a Past President of the American Association of Clinical Anatomists, coauthor of a globally distributed text (*Clinically Oriented*

Anatomy),¹ and a veteran of 35 years of teaching anatomy to medical and allied health science students, residents, and physicians, I can heartily endorse this substantial work.

Dr. Pollock and his collaborators share insights based on experience gathered over recent decades of active clinical and academic practice. A myriad of photographs of anatomical specimens, digital images of finite analysis, and Bill Winn's illustrations are the “coup de grace,” effectively bringing it all together.

Craniomaxillofacial Buttresses serves as a bridge between anatomy (structural, functional, and clinical), patient assessment, and surgical intervention. It will be a great asset to anatomists and surgeons, notably including those in training and in clinical practice, as our work continues in the 21st century.

—Arthur F. Dalley, PhD

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¹ Moore KL, Dalley AF, Agur AMR. *Clinically Oriented Anatomy*. 6th ed. Baltimore: Lippincott Williams & Wilkins; 2010

Preface

In the 10th and 11th centuries CE, buttresses able to bear immense stress loads were introduced, facilitating cathedrals, synagogues, and mosques of greater drama, size, and height. Triggered by the desire for massive roofs of limestone, mortar, and brick, the early engineering process was vetted over the many centuries of the Renaissance.

Surgeons were slow to recognize the parallels to sanctuary architecture existing in the human craniofacial skeleton, such as imbedded buttresses, “flying” buttresses (outjuttings/arches), and microbuttresses (internal struts); platforms; trusses and trajectories; and joins (sutures), each permitting the offloading of stresses created by mastication and traumatic impact. The oversight was corrected at the turn of the 20th century as Le Fort, Testut, Keen, and notably Cryer analyzed the human craniofacial skeleton. Subsequent pioneers followed their early lead and championed reconstitution of the craniofacial skeleton after trauma, even in the presence of widespread comminution.

I briefly first acknowledge the long-overlooked parallels in classical architecture and the craniomaxillofacial skeleton (**Chapter 1**) and then review the structural physics and load-bearing capacity of the craniofacial skeleton (**Chapter 2**). The section on finite analysis was contributed to significantly by colleagues Rudderman, Mullen, and Phillips and provides insight into the complexity and capacity of the craniofacial skeleton. Principles of repair are discussed in **Chapter 3**, as foundations for finesse in buttressing. **Chapters 4 to 9** offer clinical insights, with significant contributions by Drs. Schubert, Phillips, and Gossman in Chapters 5, 7, and 8, respectively.

Each clinical chapter is divided into two parts. In **Part 1**, key surgical anatomy provides an anatomical framework for assessment and operative planning. In **Part 2**, clinical presentation, radiographic assessment, and operative repair precede brief comments regarding collateral damage. This repetitive format provides the reader with clinical continuity, from chapter to chapter, regardless of anatomic site. A generous number of algorithms, medical art, and photographs enrich the text, followed by exemplary cases.

Craniomaxillofacial Buttresses is intended as an educational tool for the neophyte and the sophisticate, but, by design, has an emphasis on surgical anatomy that would form a basis for truly understanding surgical intervention. Lost in the operating theater are those without a deep understanding of anatomy of the craniofacial skeleton. What began as a proposed chapter in a book and then an historical anthology morphed into a text that would bridge a gap common to early operative experience and would offer a reference for “quick review” several days, even hours, *before* formulating the operative approach, reviewing more exhaustive texts, or seeking consultation with radiologists and other colleagues, and *before* engaging the patient in informed consent.

The text is focused on residents, fellows, and clinicians in plastic surgery, oculoplastic surgery, ophthalmology, neurosurgery, oral and maxillofacial surgery, and otolaryngology (head and neck surgery) and on the professional student, notably the anatomy graduate seeking a masters or doctorate. Physicians already in practice would find the text a refreshing review, structured to facilitate an update, despite experienced hands.

Many surgical maneuvers and details of operative repair should be garnered by further reading and experience. References therefore follow each chapter to provide ready access to key articles. A few references are annotated to aid in understanding their relative precedence. Additional bibliography then follows, citing supplementary literature that may be perused at a more leisurely pace and might elicit more extensive study.

Over the years, some publications are abandoned or unintentionally set aside, without acknowledging their visionary contribution. I have tried to appropriately recognize their originality and to restore *their* kaleidoscopic importance in craniomaxillofacial trauma management so that they may be readily referenced. Too often these first-time references are difficult to obtain in an efficient manner when the pace of practice is excessive and time of essence. Knowledge of these references allows those in training to witness the risk of wayward approaches and avoids skirting of sound surgical principles.

Acknowledgments

I am grateful to those patients who in writing have given approval for use of their preoperative, intraoperative, and postoperative photographs. The photographs, many with long-term follow-up, were chosen predominantly for their educational value. The hands-on pragmatism and serially sought anatomical expertise of the Directors of Anatomical Donations and Dieners in the Department of Anatomy, University of Michigan, merit special recognition and acknowledgment. The author also acknowledges and warmly thanks numerous colleagues for their contributions and review of various stages of this work: Robert Goldwyn, MD, Paul Manson, MD, Brian Alpert, DDS, Bruce Maley, PhD, and Arthur F. Dalley II, PhD.

John S. Turner, MD, Reed O. Dingman, DDS, MD, Joseph B. Gruss, MB, and Clinton D. McCord, MD, with whom I trained, and multiple students, residents, and fellows equally deserve acknowledgment, as they serially created the germ for this endeavor. The finesse of William M. Winn is illustrated in the refined art found throughout the text. Bill and I have achieved other projects together over many years of publication, smoothed by his intimate knowledge of the anatomy of the craniomaxillofacial region. Don Webb improved the resolution of numerous photographs, enhancing their clinical clarity and educational value. Paul G. Dimayuga on more than

one occasion rescued “lost” words, photographs, or illustrations or compressed content to make the tome more manageable.

Brian Scanlan, Timothy Hiscock, Owen Zurhellen, and the team at Thieme Medical were truly remarkable in their push to excellence. The energy, diligence, and contributions of Elizabeth D'Ambrosio and Katy Whipple deserve special mention; they were true gazelles, as deadlines were consistently met, along the way to publication.

Grateful kudos are in order too, for my wife, Janice, three children, Todd, Kerry, and Leslie, and my brother, Donald, who each, in their own way, helped nudge this tome toward completion.

Cambridge University classicist and satirist Francis Macdonald Cornford (1923) at the turn of the 20th century said: “Nothing should ever be done for the first time,” then wryly added, “Nothing is ever done until one is convinced that it ought to be done and has been convinced for so long, that it is now time to do something else.”¹ The “ought to be done” occurred long ago, the consummation of promise has been reached, and, in the Cornford tradition, it is now time to take on *another* project.

¹ Cornford, FM. *Microcosmographia Academia: Being A Guide for the Young Academic Politician*. Cambridge: Dunster House; 1923

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1 The Human Skull as a Sanctuary

■ Part 1. Buttresses in Classical Architecture

The Greek colonial temples of the 6th and 7th centuries CE featured a flat timber roof supported by massive, vertical, marble columns. Classic examples of these early sanctuaries are found at Paestum, near Naples and Salerno, Italy, in the Temples Neptune, Ceres, and Hera. The latter has been best recognized as “the Basilica,”^{1,2} because of its classical architectural features. The Temple of Concordat Akragas (Agrigento) is equally exemplary, located on a plateau overlooking the southern coast of Sicily (**Fig. 1.1A,B**).

In each instance, the weight of the timbered roofs was offloaded rather simply, to columns arranged at the periphery of the overhead structure. Over the ensuing centuries, various more complex roof designs were introduced. Vaulted roofs of limestone, brick, and mortar required concomitant change in the design of buttresses, sufficient to bear significant weight and offloads. *Barrel vaults*, by example, were introduced in the roofs of sanctuaries at Lyons (St-Martin d’Ainay), Lesterps (Civray), and Carcassonne (St-Nazaire) in southern France. *Quadrant vaults* were later erected at Clermont-Ferrand (Notre Dame du Port), Issoire (St-Paul), and Conques, all in south-central France. *Cross-vaults* were utilized at numerous locations in northern Italy (Milan/Lombardy), then Germany, northern France, and southern England³⁻⁵ (**Fig. 1.2A,B**).

In general, the offloads of these immense structures were borne by hidden ribs, vaults, architraves, cross-struts; obscure internal piers, built-in butts; more obvious capitals and columns, pillars, and struts of varied sort; and thickened walls and counter-walls. Vertical pilasters and ribbing were adorned by gabions, caryatids, and telamones, featuring female and male sculptures.

As a means of transmitting even greater stress loads of the massive roofs, further permutations of the buttress principle were required, including placement of the buttresses beyond the primary sanctuary to assorted outlying edifices. This permutation is well represented by the *flying buttresses* at the Abbey Church of Cluny III (Saone-et-Loire, near Macon, in east-central France), built in the 11th century CE, and by the Duomo, the cathedral of Milan (in northern Italy), initiated in 1386 (**Fig. 1.3**).

Gothic builders enjoyed wide use of the *flying buttress* and its associated support structures in cathedrals at Notre Dame (Paris, France), Chartres (Eure-et-Loir, southwest of Paris, in central France), Amiens (Saint-Acheul, in the north of France), and at Westminster Abbey in London, England (**Fig. 1.4A,B**).

The *flying buttress* allowed load forces to reach the upper part of the vertical pillar, and then the lower portion. The pillar was usually capped, by-weighted, and, in some cases, made strikingly decorative with peripheral

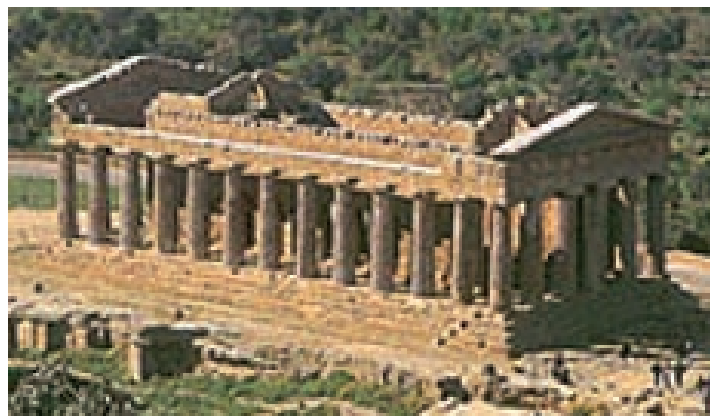


Fig. 1.1 (A, B)



Fig. 1.2 (A, B)

pinnacles, statues, elaborate brackets, crockets, or knot-crockets. Other adornments, such as gargoyles, gabions, or baldachinos, were featured at the midheight of the buttresses but bore no significant load forces (Fig. 1.5A,B).

The utilization of buttresses and the principles of buttressing flourished between the 12th and 14th centuries. Notably, the *flying buttress* and other structural embodiments allowed sanctuaries to reach profound height and size, diminished the risk of conflagration associated with

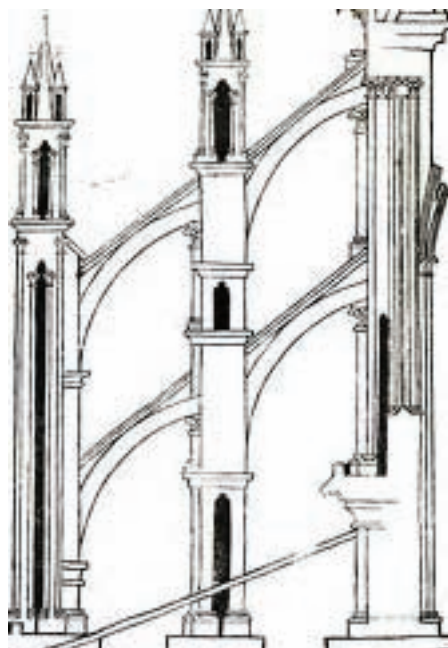


Fig. 1.3

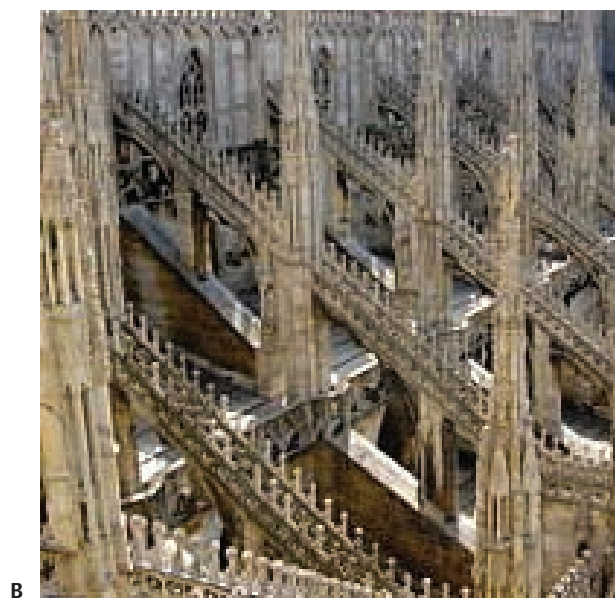


Fig. 1.4 (A, B)



Fig. 1.5 (A, B)

timber roofs, and permitted spacious, vaulted aisles. Cut-outs for clerestory windows offered the secondary benefit of improved internal lighting (Fig. 1.6A,B).

■ Part 2. Buttresses of the Craniomaxillofacial Skeleton

Parallels to sanctuary support systems are apparent on inspection of the craniofacial skeleton: vertical buttresses and trajectories, horizontal platforms and shelves, struts, trusses,

and outframes (arches) allow offloading of the stress of mastication and the impact of trauma. These features, only slowly comprehended in an historical sense over the centuries, aided development of biomechanical concepts and influenced methods of craniofacial repair after trauma.

Ancient anatomists revered the hand as God's "most profound creation"^{6,7} and generally gave little attention to study of the facial skeleton. Ancient Greeks (distinctly Galen) were exceptions to this focus, and, notably later, during the Renaissance, Leonardo da Vinci and Andreas Vesalius refined skeletal depictions of the cranium and face (Fig. 1.7A,B).



Fig. 1.6 (A, B)

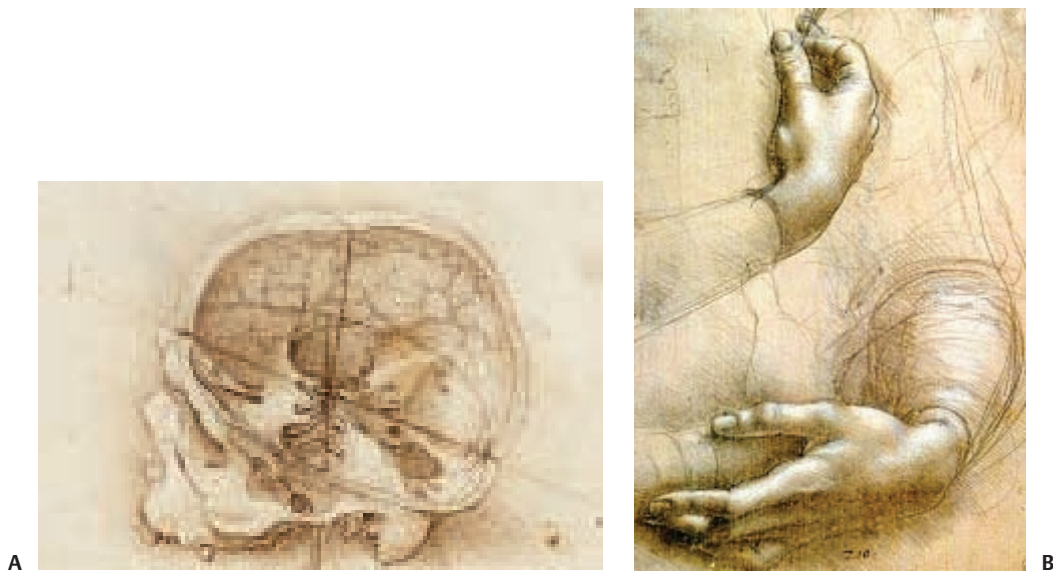


Fig. 1.7 (A, B)

Modern awareness and understanding of craniofacial structure was heightened when Rene Le Fort in 1901 described “areas of inherent weakness and comminution” across the bony midface, after impact.⁸ Le Fort, of Paris, France, perceived bones of the midface to “hang like a curtain,” some “delicate and spongy,” and some in columns or “blades of bone more compact”⁸ (Fig. 1.8A).

Jean-Leo Testut (1849 to 1925), Professor of Anatomy, University of Lyon, France, a decade later, reversed the architecture described by Le Fort. Testut instead pictured a

framed assembly of “dense pillars” beneath the cranium. Interspersed between the pillar-like struts, according to his assessment, were “zones of weakness”⁹⁻¹¹ (Fig. 1.8B,C).

In either case, the dense condensations of craniomaxillofacial bone, recognized today as *buttresses*, were not defined in these terms, nor was their role as load-bearing pathways understood. It remained for Henry Cryer of Philadelphia, Pennsylvania, to identify the seven craniomaxillofacial buttresses, “descending,” as he described it, “from the walls of the cranial vault above, to the maxillae



Fig. 1.8 (A–C)

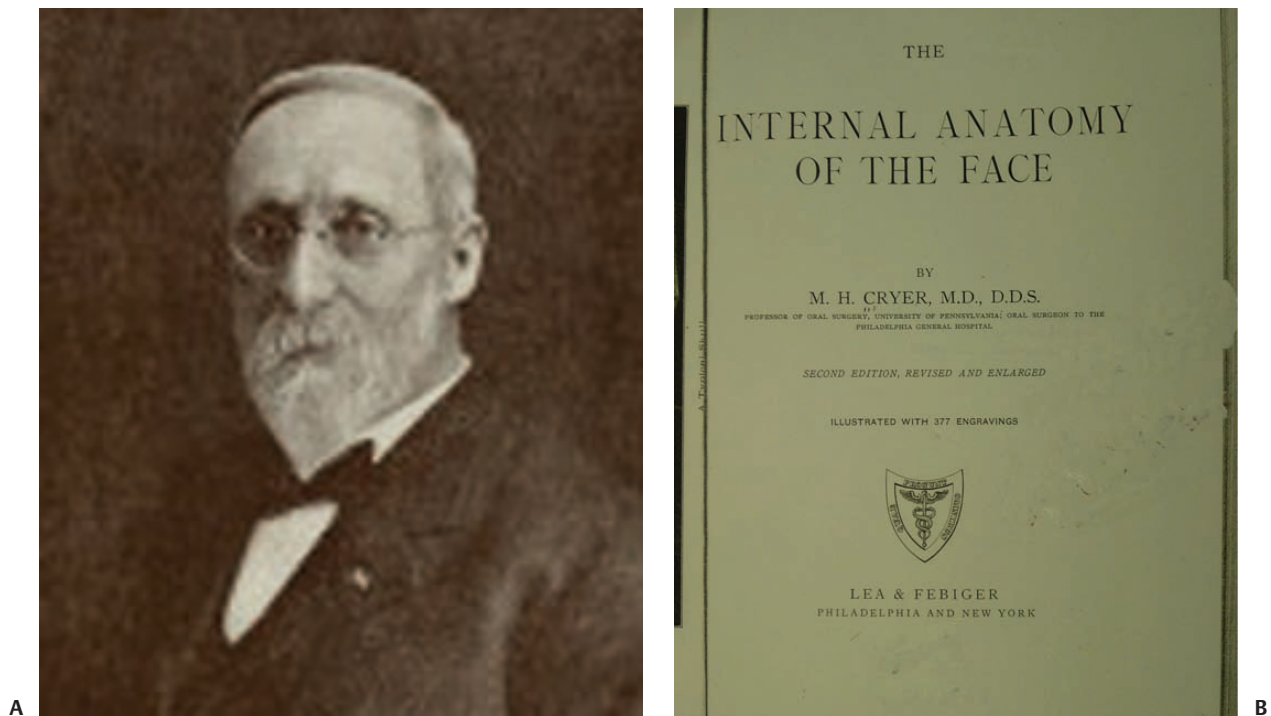


Fig. 1.9 (A, B)

[jaws] below.” He recognized four “outer” (anterior) and three “inner” (posterior) buttresses, that strengthened the cranial vault and palate. The anatomic components of each of the seven buttresses are identified in Cryer’s 1916 text, *The Internal Anatomy of the Face*, published in Philadelphia by Lea & Febiger¹² (**Fig. 1.9A,B**).

Cryer perceived the “nasal septum, especially that portion formed by the vomer,” to be a “*flying buttress* to the sphenoid bone” and considered the “zygomatic arch a *flying buttress* that supports the upper jaw.”¹² Like Testut before him, Cryer found the bone interspersed *between* the

buttresses and “flying” outjuttings to be delicate, fragile, and, he argued, vulnerable to injury.

Cryer’s original description of the basic craniomaxillofacial architecture has been modified only slightly in the past near-century.^{13–22} Sicher (**Fig. 1.10A**), for example, emphasized the pith of horizontal platforms (such as the palate, orbital floors, and orbital roofs) in human facial form.^{14,15} Dingman (**Fig. 1.10B**) and Natvig duly noted the buttressing role of the palatine struts.¹⁶ And, Ferré and colleagues drew attention to the convergence of structural bone and nonosseous entities at the base of the sphenoid sinus (central cranial base).^{21,22}



Fig. 1.10 (A, B)

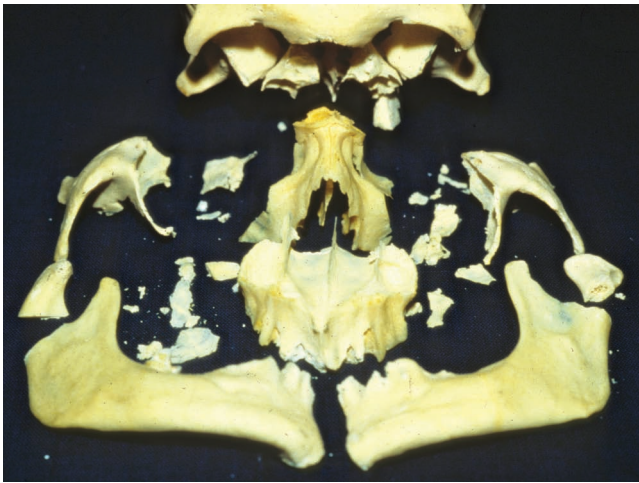


Fig. 1.11

Direct interosseous repair of bone fragments began in 1846, first in the mandible (Buck, Fouchard, Kinloch, Gilmer, Kazanjian) and then in the maxilla (Gillies, Converse, Adams, Rowe, and Dingman). They and Muller, Luhr, Merville, Schilli, Champy, Couly, Michelet, and others in Europe recognized the relevance of reconstitution of the buttresses after craniomaxillofacial trauma.

By applying craniofacial appliances in the proper location, load-bearing forces, it appeared, could be effectively redistributed, and callous-free osteosynthesis could be encouraged. After reports by Huelke, Manson, Donald, Zide, Gruss, Jackson, Munro, Klotch, Van Sickels, Ellis, Alpert, and many others, direct repair became a tenet of craniomaxillofacial repair, with or without comminution^{23–92} (Fig. 1.11).

■ Key Points

Parallels between sanctuary architecture and craniomaxillofacial skeletal form were recognized at the turn of the 20th century by pioneers such as Matthew Henry Cryer. “The skull,” as emphasized by Robert Goldwyn, “is our sanctuary, and there are buttresses” in a multitude of shape and character. A myriad of colleagues in time, armed with this rather profound realization, championed direct repair of bone fragments, even after comminution, and identified fracture pathomechanics and the subtleties of impact distribution. Clinical outcomes progressively improved after reconstitution of the craniomaxillofacial skeleton, first after low-velocity and then even after high-velocity impact.

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2 Structural Physics of the Craniomaxillofacial Skeleton

With contributions by Randal H. Rudderman, Robert L. Mullen, and John H. Phillips

■ Part 1. Basic Craniofacial Biomechanics

The structure of the craniofacial skeleton¹⁻³ is relatively delicate and vulnerable to the impact of new physiologic loads, whereas in adjacent areas, such as the skull, the bone is thick and comparatively robust. All areas participate in the absorption of force loads, but logic would suggest that reinforced areas (buttresses) transfer and then release greater force loads during normal function and are less vulnerable to injury. In the mid-20th century, Gurdijan and Webster studied deformation of bone by first applying lacquer (so-called Stresscoat®) to the surface of bone and by then employing various, controlled forces.^{1,2} Gurdijan and Webster did not have the initial goal of studying craniofacial fractures but demonstrated that loads applied in a given area are routinely and widely distributed *throughout* the craniofacial skeleton,³ even with low-velocity impact.

High-speed computer (finite element) analysis reveals the functional behavior of craniomaxillofacial structure at more diminutive levels than those possible in the mid-20th century. Upon the application of measurable load forces, creation and flow of *facial force equilibrium circuits* of stress to and from the components of the craniofacial region (collagen matrix, dentition, cartilage, muscle, tendon, fascia, and notably bone) can now be demonstrated using finite computer models.⁴⁻⁶ The distribution of circuits of stress to and from the cervical spine during force applied to the craniofacial skeleton can be speculated but is yet to be demonstrated.

The admix of thick and thin, first noted by Le Fort, Testut, and Cryer,⁷⁻⁹ makes the craniofacial skeleton subject to torsion, rotation, translation, and other complex geometrical events^{1-3,10-15} after low-velocity and particularly after high-velocity impact. These seven buttresses of the mid-face, by example, are often sheared just after their ascent from the palatal platform, creating what Le Fort called a Level I fracture (**Fig. 2.1**). With higher velocities of impact, more obscure patterns of injury are witnessed.

Terms Essential to Understanding the Biomechanics of the Craniofacial Skeleton

Only biomechanical perspectives germane to craniofacial anatomy and repair will be presented in this chapter.^{16,17} Terms common to engineering are reduced to a pragmatic level, with some admitted, but acceptable, risk of

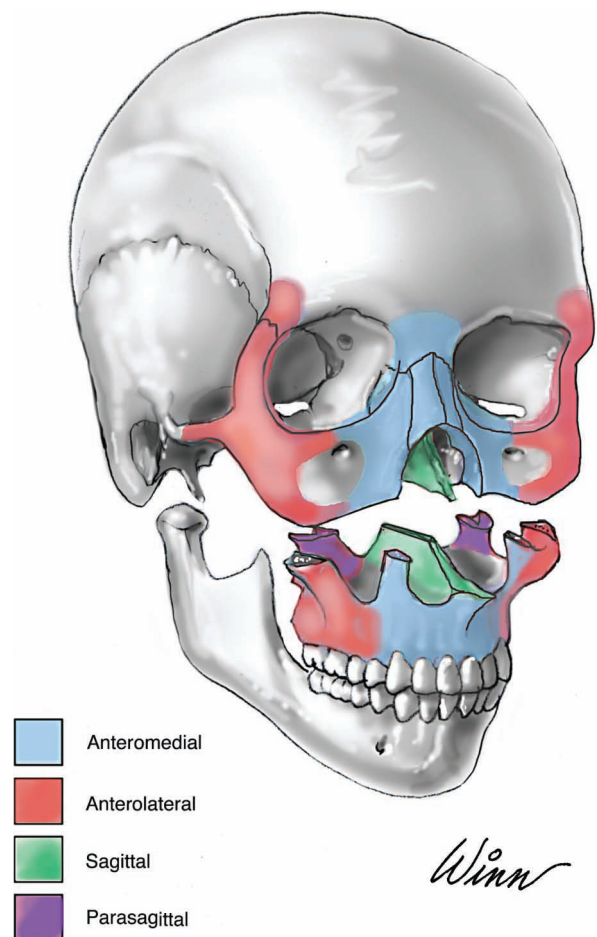


Fig. 2.1



Fig. 2.2

oversimplification. That said, all structures in nature undergo a physical, geometrical change in space when exposed to "force." The craniofacial skeleton is no exception. Alteration of length is described as "tension" or "compression" and is defined by the relative change in position of the atoms of a given material. "Tension," or "tensile force," results in atoms moving further apart, in effect acting to microlengthen or microstretch a material. With "compression," or "compressive force," the atoms move more closely together, acting to diminutively shorten linear dimensions of a material.^{5,12,13} "Tension" patterns in craniofacial bone have been arbitrarily shown by various means, and they are reproducible. The

patterns of "tensile force" in the accompanying mandible follow the application of force in the region of the anterior body near the *right* mental foramen, with the condyles fixed and immovable. The inward bending of the right body leads to lines of "tension" at the right inner cortex, the inner cortex of the ipsilateral condyle, and the outer cortex below the opposite condylar neck. The tension lines, in this arbitrary system, that may be inconsistent with a functional, living system, have been darkened to dramatize the imposed patterns¹² (Fig. 2.2).

"Torsion" is rotation caused by tensile and compressive forces that act as a unit to create displacement. A "displacement force" (previously referred to as a "shearing force" by Huelke and Harger¹²), thus, can be pictured as causing one part of an object to slide over an adjacent part (Fig. 2.3).

"Torsion" is suspected as a key component, by example, when comminution of the buttresses of the midface occurs during high-velocity impact and displacement of the intact palate and alveolus beneath the periorbit and cranial base occurs. Torsion of the face upon a stable cranium interrupts the vertical and horizontal buttresses, creating a "twisted skull" (Fig. 2.4).

The terms "stress" and "strain" are often used synonymously, but the terms are not in any way interchangeable. "Strain" refers to the elongation or the shortening of the linear dimensions of an object when it is under tension or compression; "strain" is expressed in a dimensionless ratio, as the amount of linear deformation per unit of length. By contrast, "stress" is a measure of the intensity of applied force, and it is expressed in units of force per unit area, most often as pounds per square inch.^{12,13,18,19}

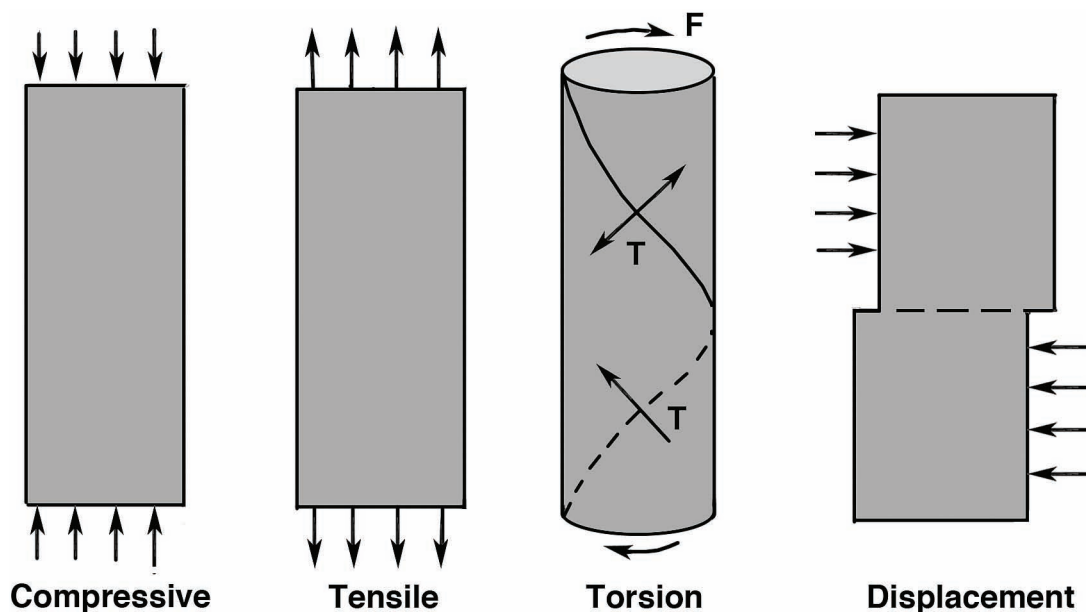


Fig. 2.3



Fig. 2.4

When there is “strain,” there is by definition a measurable deformation. “Tensile-strain” is therefore the elongation of an object by tensile forces, and “compressive strain” is shortening of an object under compressive force, as measured by increasingly sophisticated methodology that is able to define the “stress-strain relationship” of various materials, both commercial and biologic. But “stress” merely refers to the existence of intermolecular forces that are generated by the action of two objects on one another, exerting forces of equal magnitude along the same axis but in a different direction.⁵

“Strength” refers to the capacity of materials to resist failure.²⁰ Thus, “tensile strength” refers to the capacity of a material to resist the action of tension (“tensile force”). “Compressive strength” depicts the capacity of a given material to resist compression (“compressive force”). “Stiffness” is the capacity to resist motion from compressive and tension forces. And, “elasticity” refers to the ability of a material to return to the shape that was present prior to the application of force. The material able to resist permanent change uses the energy stored during loading to return to the preloaded shape.^{4,5,12}

Load Conditions

The craniofacial skeleton functions under a myriad of load conditions that include “routine” forces triggered by speech, swallowing, facial expression, and contact of the dental segments of the upper and lower jaws while eating food (mastication). Measurable changes in craniofacial geometry occur with the “stress” of each of these and other actions, dramatized by low- and high-velocity impact.^{12,13,18,20}

Muscle and tendon are relatively elastic, changing shape even with small loads, as one might expect, only to readily return to their original shape. Craniofacial bones have been shown to sustain greater load forces, yet also retain the ability to return to prior architectural form. This return to prior form and function is empirically recognized in the human cranium and face, where change is not discernible, on a daily basis. Numerous muscle groups appear able to influence craniofacial, particularly midfacial and orbital, structure and their more delicate fragments after injury. Muscles bias the reduction and repair of dislocated bone, whether or not proper stabilization is achieved. The load patterns created by

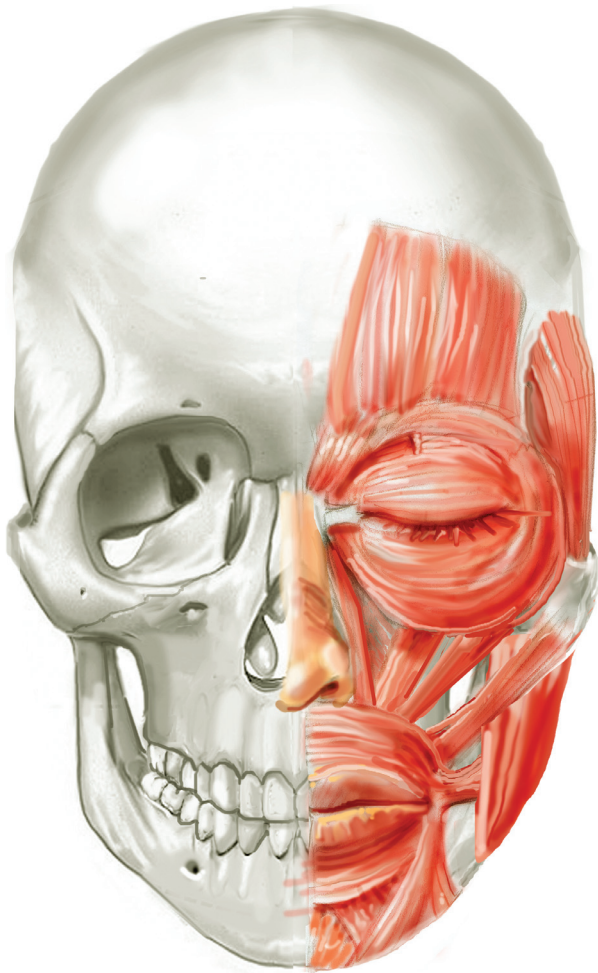


Fig. 2.5

the composite action of the musculature has yet to be defined and is “neither obvious, nor always predictable”⁵ (Fig. 2.5).

Studies of Cortical Grain

The tendency of bone decalcified by ethylenediamine to split in a specific direction when punctured and stained with India ink is detailed in the works of Benninghoff, Seipel, Tappen, Evans, and Dempster and their colleagues in the 20th century.^{14,21–32} Their studies reveal planes, columns, arches, buttresses, and saddle ridges with elongated grain; troughs with defined transverse demarcation; concavities with distinct circular grain; and specific edges, eminences, and spines in the craniofacial region. These reproducible features of the skull and face are noted in a field of relatively complex patterns in areas such as the outer cortex of the cranial vault (Figs. 2.6 and 2.7A–E).

The structural presence of barreled arches, elliptical domes, saddle ridges, and troughs at the cranial base, and columns of thicker bone arising from the palatal platform to reach

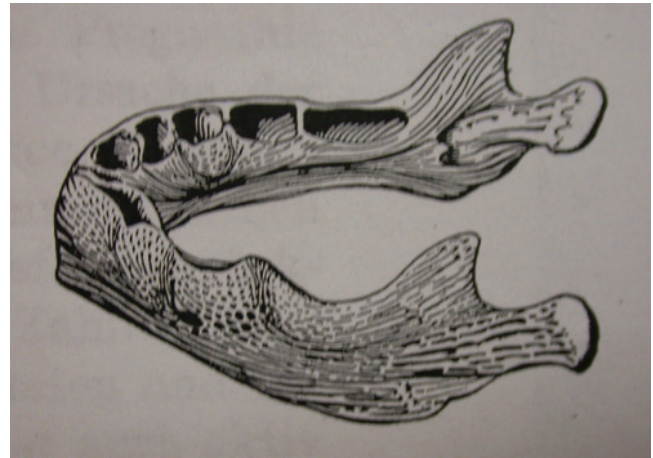


Fig. 2.6

them, allows speculation regarding strategic function of the craniofacial skeleton. Forces applied in strategic areas can be interpreted, by one example, to show that “tensile strength” of the craniofacial skeleton is greater *along* the grain than *across*.^{25,27,33} Origin of cortical grain is unclear. Cortical grain and areas of “tensile strength” could be genetically determined by primary shifts of plates of embryologic mesoderm, leading to thick and thin anatomic segments, each able to bear different directional loads, according to one hypothesis. According to another hypothesis, “creation of grain” is due to secondary adaptation during preadolescence and beyond. Dempster,³¹ and Enlow and Bang,³⁴ for example, suggest that “trajectories,” such as those of the mandible, “develop in ossified collagen-matrix as a lifetime response to functional, intermolecular stresses (Wolff’s Law).” In this adaptive scenario, “craniofacial bone is serially subjected to micro-tension, compression, bending, and shearing, then resorbed, replaced, and reoriented, until a multitude of eminences, columns, and fossae are created, to reach the form, texture, and function of adulthood.” Accepting the Dempster-Enlow-Bang adaptation hypothesis as the more probable of the two hypotheses, bone architecture is influenced by the ever-increasing size of brain, orbital contents, and tongue by ongoing formation of new cortex and cancellous bone, by evolution of sinuses and their microbuttresses, by adaptation of craniofacial structure to dentition and occlusal contact, and finally by progressive imposition of gender specialization. Perhaps both primary *and* adaptive etiologies are at work, with adaptation having the greater effect in the creation of craniomaxillofacial form.

Lacquer Studies

High tensile forces have been applied to randomly selected, fresh cadaveric skulls and mandibles after the application of a stress-sensitive lacquer (Stresscoat[®]) to both external and internal surfaces.^{1,2,18,35–37} With adequate force, the cracks

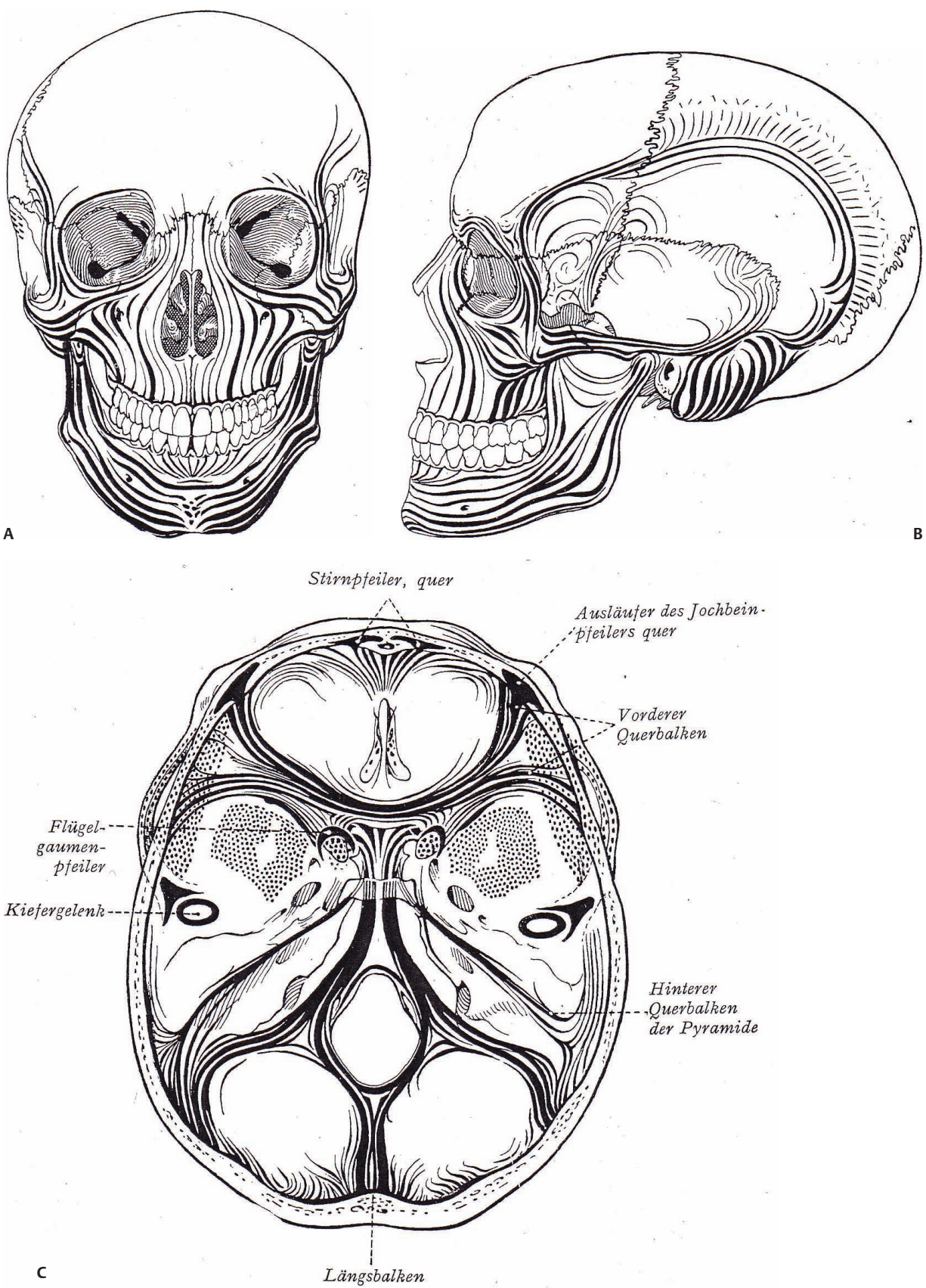


Fig. 2.7 (A-C) (Continued)

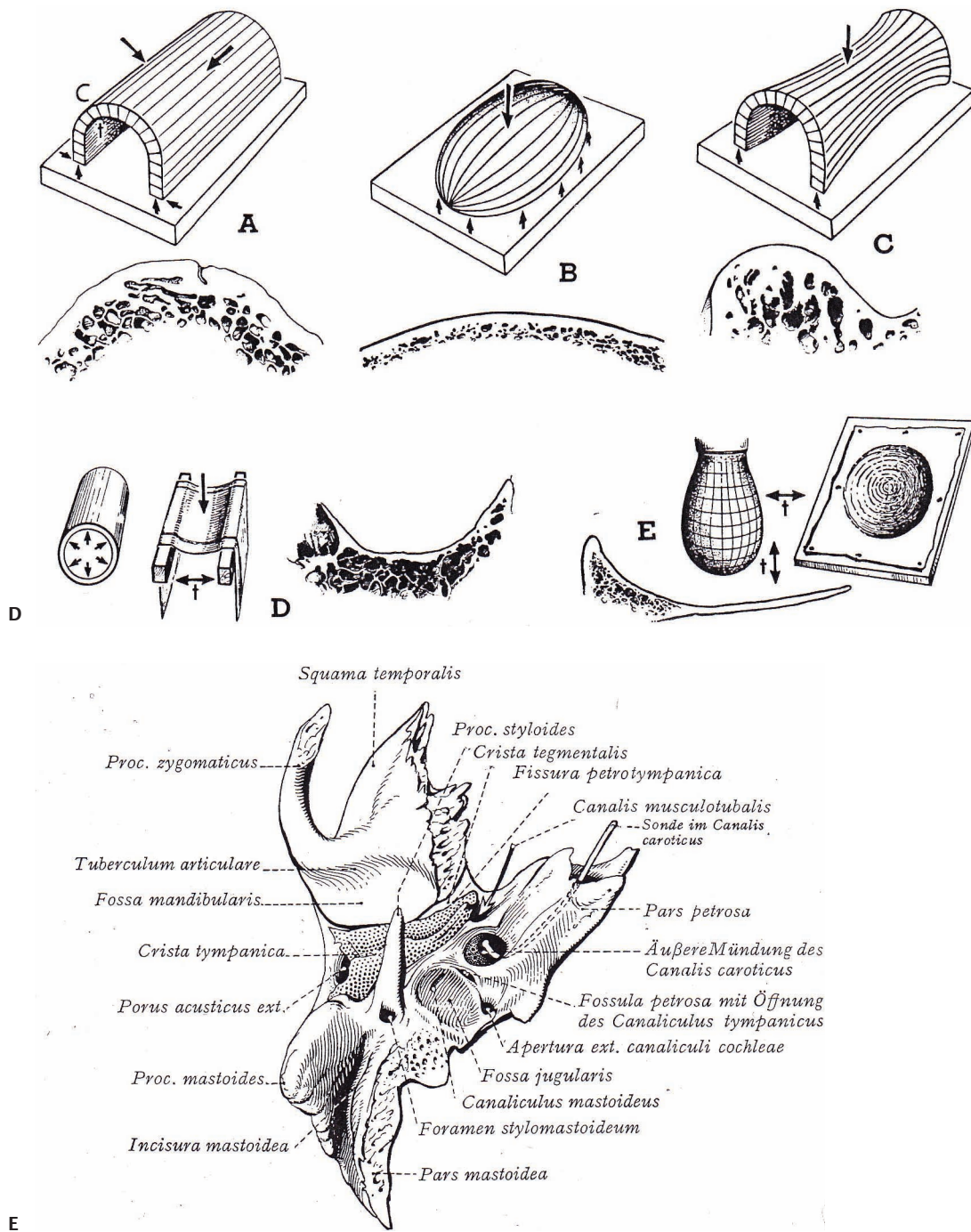


Fig. 2.7 (Continued) (D, E)

due to tension failure appear in the lacquer and are dramatized by red or India ink dyes. Patterns within the lacquer, it turns out, correlate reasonably well with the common locations of fractures in the clinical setting. Studies using the lacquer technique suggest that loads applied at a given point are distributed *throughout* the craniofacial skeleton.

High-Speed Cinematography

The application of lacquer to the inner and outer cortex of bone also delineates the areas of mandible prone to tensile strain, as noted in the preceding section, without destruction of the bone specimen. Validation of the lacquer stud-

ies is gained by close examination of high-speed film, as metal cylinders descend at a controlled rate to impact the symphysis of the mandible and other areas of the craniofacial skeleton. In the case of the mandible, the condyles are either fixed or allowed to move freely in their base plates. The film, taken at 16,000 frames per second, records the result of impact at the symphysis of the mandible and other areas of the craniofacial skeleton, as the cylinders descend at 3- and 12-foot-pounds^{12,38-43} (Fig. 2.8).

High-speed film studied in slow motion reveals that fractures consistently begin on the lingual surface of the mandible after a direct blow to the "chin point." Other impact sites along the anterior segment of the mandible (parasymphysis, body, or angle) bear similar results: *fractures begin on the inner cortex, opposite application of*

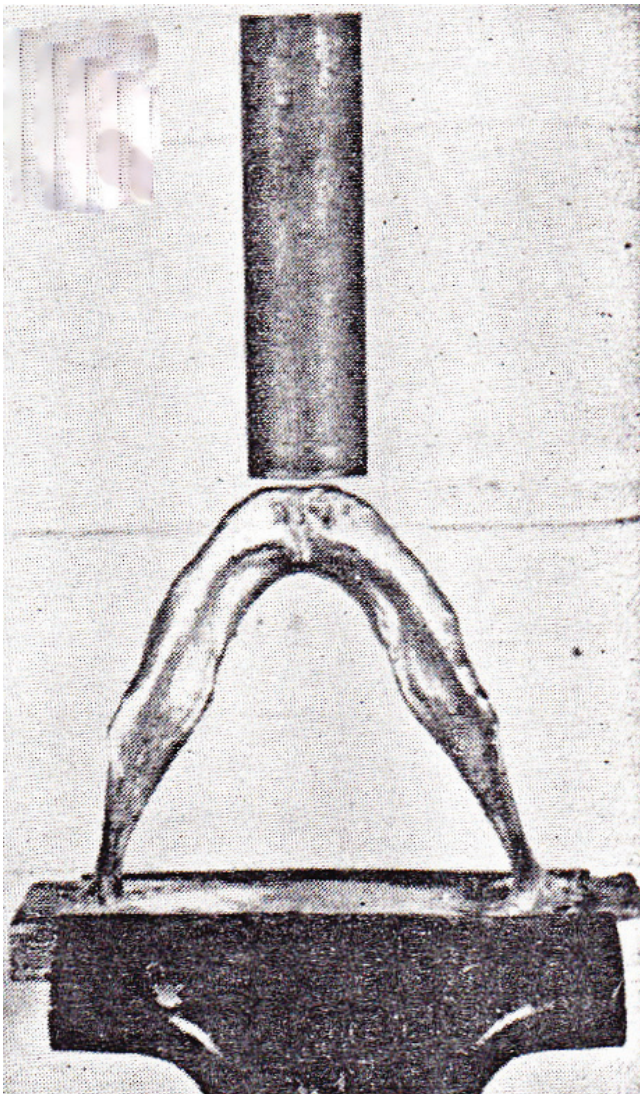


Fig. 2.8

a compressive force to the outer cortex. When "strain" overcomes the strength of the structure, evidence of fracture is visualized (Fig. 2.9).

When the "strain" of bending is provoked in other regions, such as the angle of the mandible or the neck of the condyle, propagation of fracture follows.

The condyle(s) are locked into position with pins, mimicking the arbitrary clinical circumstance in which the condyles are forced posteriorly into the glenoid fossa with impact, and movement is constrained by collateral ligaments of the joint. In other instances, when pins in the condyle(s) are avoided, the mandible is allowed to shift, and one or both condyles are free to move in their base plate, as it may in certain circumstances (Fig. 2.10).

When both condyles are pinned and a direct midline impact is applied, bending and tensile strain are noted on both the medial and lateral aspects of each condyle. Bilateral subcondylar fractures are common under these circumstances. But, when the impact is moved off center to involve the mandibular body (and thus not in the midline), bending and tensile strain predominantly reach the *outer* cortex of the ipsilateral condylar neck and the *inner* cortex of the neck of the opposite condyle.

When the condyle on the side of impact is *free to move* (and the condyle opposite the impact is *immobile*), bending and high tensile strain are noted on the *medial* aspect of the opposite condylar neck (after impact of the mandibular body). When the condyle on the side of impact is rigidly secured (and the condyle opposite the impact is mobile), bending and tensile strain are more apparent on the *lateral* aspect of the opposite condylar neck (Fig. 2.11).

Maxillary fractures are produced by application of loads above the palatal platform. Marked comminution, as noted by Le Fort at the turn of the century,⁷ is revealed as the midfacial segment is forced inwardly and downwardly. The maxillary bone fails after inward bending of the thin bone that constitutes the lower anterior face of the maxilla and the lower portions of the buttresses as they arise from the palate.

Malar and zygomatic arch fractures are provoked by direct impact to the zygoma or one of its four processes. As the thin anterolateral wall of the maxillary sinus succumbs and the frontozygomatic suture is cleaved, film records displacement of the zygoma in two dominant patterns: "in and back" or "down and out" (see Fig. 8.30B in Chapter 8). Rotation of the zygoma occurs when blows to the malar prominence are oriented obliquely or when the zygomatic arch quickly succumbs to impact. With extreme force applied to the opposite side of the face, the zygoma may be fractured by the shifting midface segment.

Evaluation of orbital fractures is also possible by high-speed cinematography.¹² After direct blows to the eyeball, the bilge of the floor bends downwardly (as first proposed by Pfeiffer⁴⁴), eventually provoking the orbital bone, in the

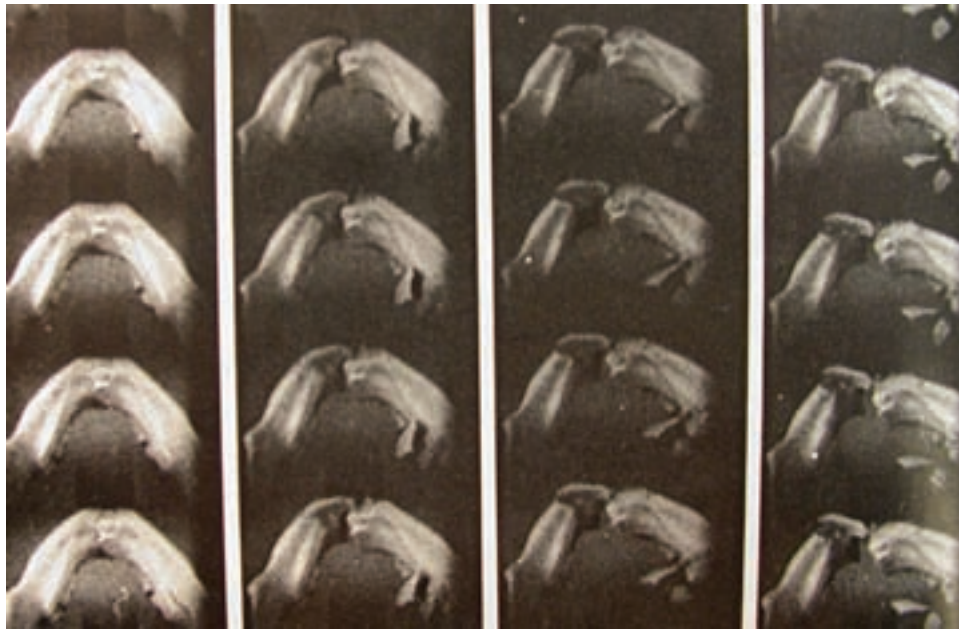


Fig. 2.9

words of Huelke and Harger,¹² to “explode like a balloon.” High-speed cinematography and other bench studies suggest three probable mechanisms of orbital injury: 1) the hydraulic effect of load forces applied to the orbital contents convey to the orbital walls; 2) direct buckling of the walls after deformation of the orbital frame; or 3) both.^{12,45–49} Further refinements in our understanding of the physics of orbital injury are sure to follow the combined use of finite element and strain-gauge analysis.⁵

Clinical experience suggests that the mandible is capable of distributing load forces to multiple sites, and load forces “reach” areas of similar or near-similar susceptibility.

Fractures, by example, are concomitantly witnessed in one or more subcondylar regions, the symphysis or parasymphysis, and the angle or body of the mandible. Huelke and Harger¹² conclude that all craniofacial bones fail under *tensile force* when they are subjected to sufficient impact.

Strain-Gauge Assessment

Small electronic devices (called strain gauges) are able to record one-dimensional strain between two points.^{12,13} The “elastic limits” of bone, as it undergoes progressive

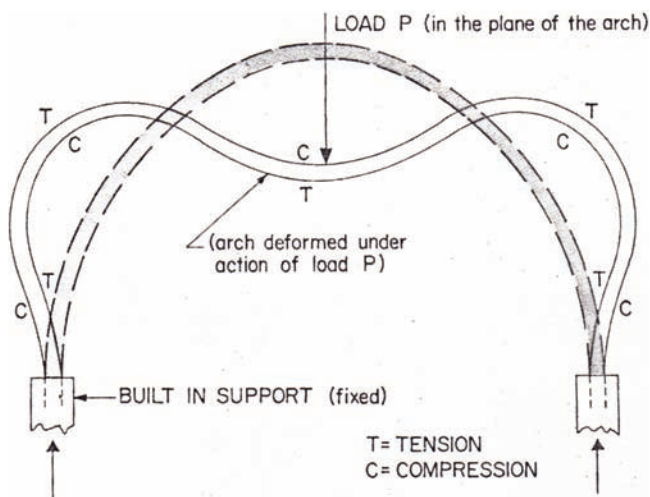


Fig. 2.10

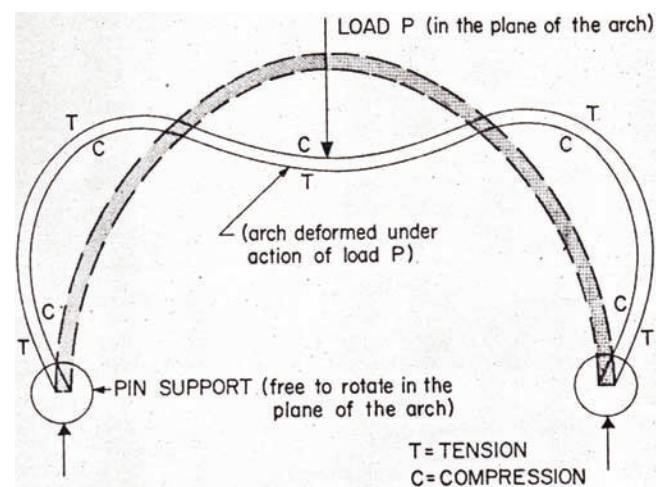


Fig. 2.11

deformation, can thus be evaluated during a very complex combination of events that lead to fracture. At a definable level of tensile stress, a “yield point” is reached in each craniofacial area, and little additional force is then required to initiate and propagate a fracture.⁵

As “elastic limits” are readily reached in the central upper face, the lower midface, and orbit, in great part due to the presumed limited tensile strengths of the sagittal buttresses nearby, fracture occurs. The anterior and middle cranial vault (frontal, sphenoid, and temporal bones) require higher loads prior to fracture compared with other areas of the craniofacial skeleton. Yoganandan and Pintar suggest that the biomechanical properties of the cranium do not depreciate significantly with age, in contrast to other bones, such as the pelvis.¹⁵

Boxing

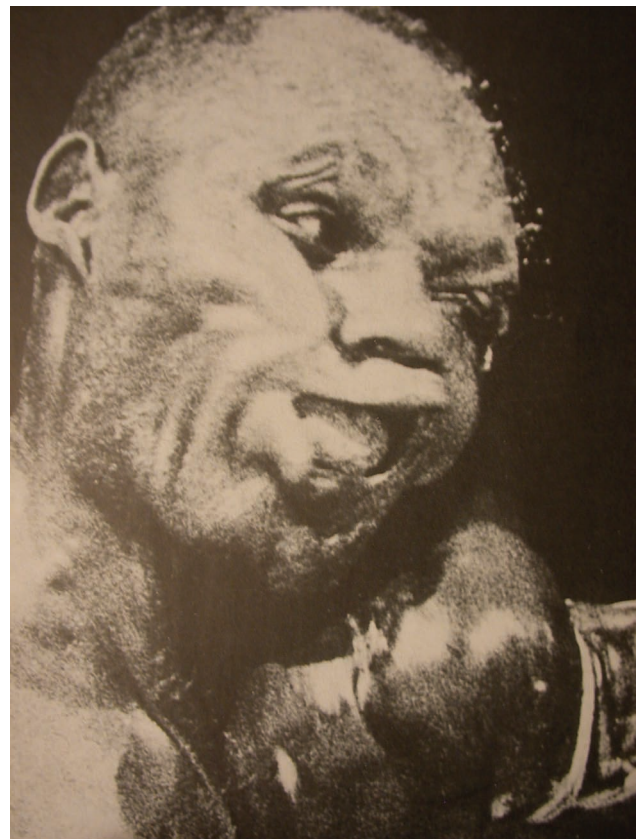
No sport implies the broad distribution of load forces throughout the pancraniofacial soft tissue and skeleton after impact better than boxing.^{50,51} Although fractures after professional boxing are uncommon, the directional distortion following gloved impact is appreciated in still photographs taken during the professional middleweight contest between Willie Vaughan and Ralph “Tiger” Jones, the fight between Florentino Fernandez (the “Cuban Ox”) and Johnny Featherman, and the heavyweight championship fight between Rocky Marciano and Joe Walcott. For enthusiasts preferring video, various productions are available for viewing⁵² (Fig. 2.12A–C).



A



B



C

Fig. 2.12 (A–C) (A courtesy of United Press International; B and C courtesy of the Associated Press.)

■ Part 2. Implications of Finite Element Analysis

Facial architecture has historically been perceived to be a buffer to injury of supra-adjacent structures. The craniofacial buttresses act as an accordion in this proposed scenario, collapsing after impact to “cushion” the neurocranium and protect the cervical spine.^{3,53}

The buttresses and flying buttresses “not only,” in the words of Cryer, “support direct forces acting externally, but also dissipate and diffuse shocks which would otherwise be transmitted to the cranium”⁹ (Fig. 2.13).

This perception *seems* to correlate with the description of anatomic struts, descending from the cranial base to the palatal platform, by Testut, Cryer, Tandler and Sicher, and others.^{7–10} Support for this concept was endorsed by the authors of numerous subsequent clinical studies and was *intuitively* reinforced when plates and screws were introduced to reconstitute the craniofacial buttresses, restoring surface geometry and presumably reestablishing the distribution of load forces along these anatomic segments. Thin structures of the anterior, medial, lateral, and posterior maxilla are *assumed by this historical perception* to play a modest role in the restabilization of craniofacial structure (and the distribution of load forces) after repair.⁵

Lacquer impact studies and cinematography of the mid-20th century, though relatively ignored until recently, suggest a very *different* course of events, such that loads applied to the facial skeleton are freely and widely distributed *to and from* the cranium.^{1,2} Load forces, according to this hypothesis, have a pancraniofacial distribution, directly engaging the neurocranium and collateral areas.^{3,15} Extension of load forces to and from the cervical spine seems probable,^{54–57} but it is not yet proven.

This elegantly complex mechanism of load distribution *throughout* the craniofacial skeleton after impact is supported by selected studies (both in cohorts of survivors and notably non-survivors) over the past 60 years and by

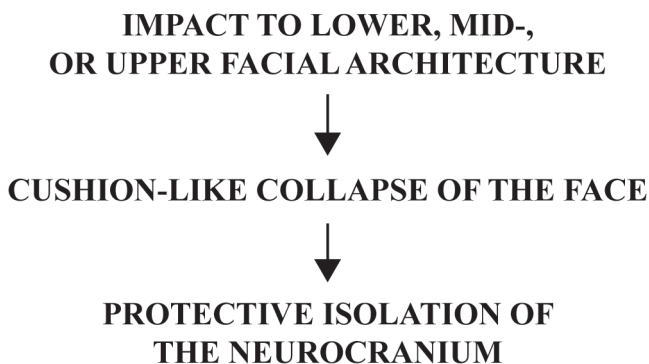


Fig. 2.13

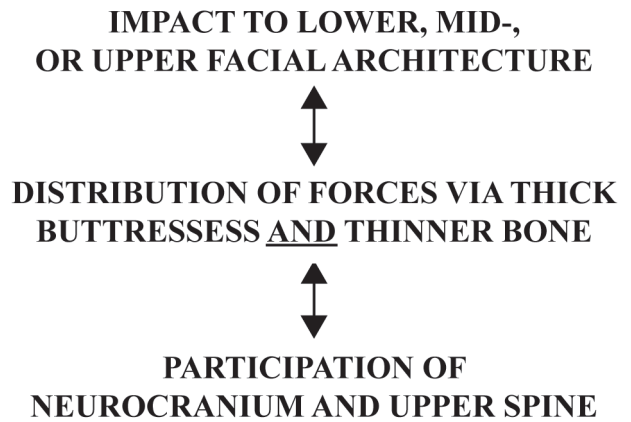


Fig. 2.14

recent *finite and strain-gauge analysis*, as reported here and in pending publications^{15,59,60} (Fig. 2.14).

All components of the pancraniomaxillofacial and pancraniobasilar skeleton, according to structural theory, participate in a balanced distribution of load forces. The contributions of the thin bone of the craniofacial skeleton are now less readily discounted as trivial.

A Current Finite Analysis Model

A computer model of the craniofacial skeleton captures the geometry of the entire skull and face by fixing the cranial base at the foramen magnum; the spine has been excluded. Anisotropic bone properties are included from multiple locations. The bite position in the computer model illustrated is in the area of the left canine, and the masseter musculature is simulated bilaterally for each bite condition. (“Compression” and “tension” values are related to the submental-vertex-axis. Red areas are “tension zones,” and blue “compression zones.” Regions in green depict the least stress.)

In this instance, the chosen left canine bite location triggers greater “tension” along the ipsilateral lingual cortex of the body and angle, “compression” along the contralateral lingual cephalad surface, and “compressive” stress in the midface along the four (medial and lateral) maxillary buttresses. The pattern in this case suggests concomitant “compression” of the central face, “compression” of the medial side of the lateral orbital rim, and “tension” at the ipsilateral lateral orbital rim (frontal process of the zygoma) (Fig. 2.15A).

In another illustration of load distribution, *bilateral* “tension” and “compression” can be provoked in many circumstances and measured using the computer model.

“Compression” is noted not only in the left body and symphysis of the mandible, ipsilateral to the bite load (pictured in blue) but is also captured in some regions of the

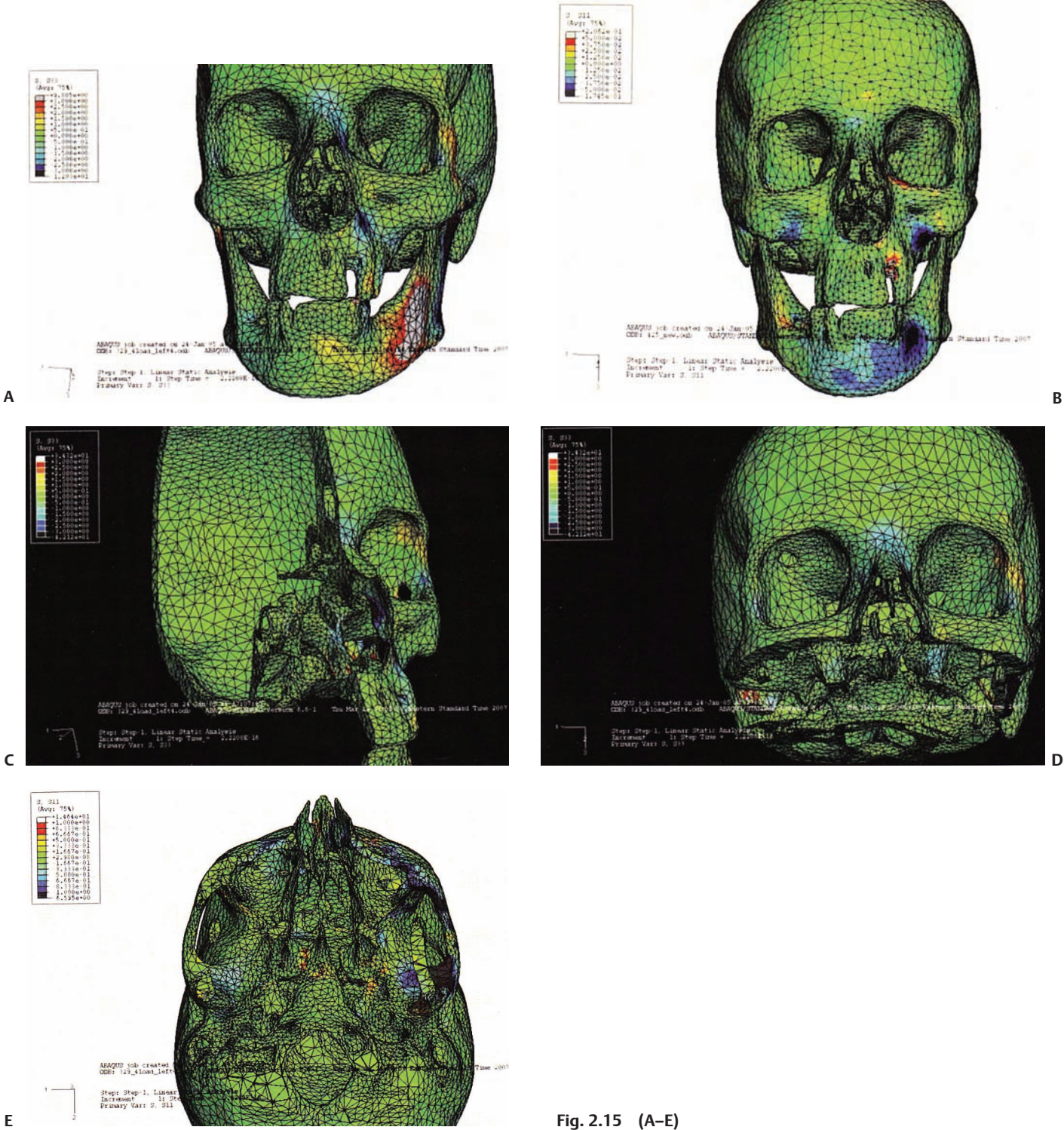


Fig. 2.15 (A-E)

contralateral mandible. Here also, the midsection of the lateral buttress of the midface is compressed, most notably on the same side as the bite load. The nasion is compressed below the frontal boss as noted, but in this case, the compression is in the midline. In addition, the ipsilateral infraorbital rim exhibits signs of “tension” along its superior surface, again supporting upward and cephalad finite displacement of the midface with the left-sided bite load (**Fig. 2.15B**).

Zones of “tension” and “compression” are also revealed in submental vertex planes. In the upper view, vertical “compression” is present along the posterior medial buttress during loading of bite forces. The sagittal plane demonstrates additional “compressive stress” (depicted in blue) along the right medial wall of the maxilla and vomer during loading (**Fig. 2.15C,D**).

During the same canine bite force, “compression” (in blue) is elicited simultaneously in both zygomatic arches and in bilateral regions of the skull base, including the temporal bones. The distribution of concomitant force to the subjacent cervical spine is not known (**Fig. 2.15E**).

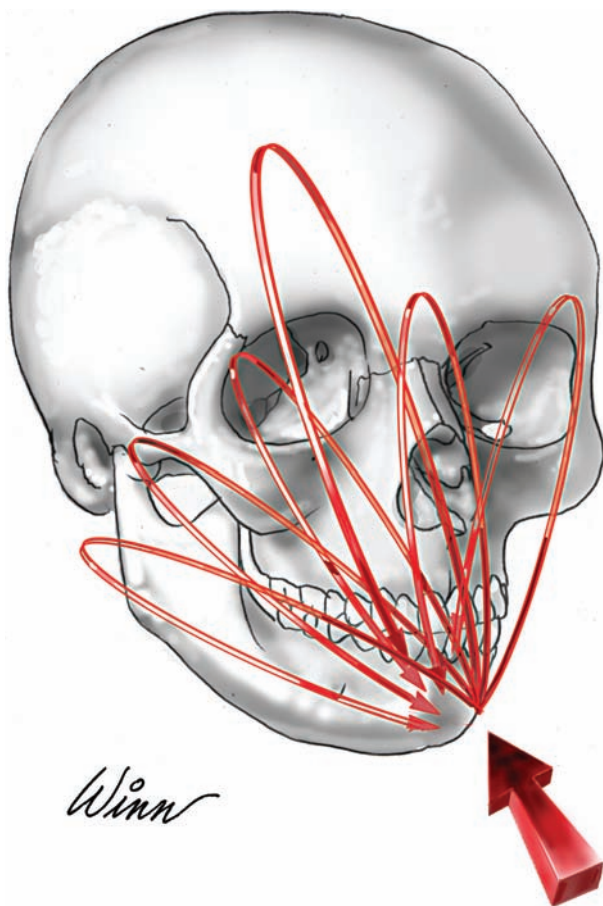


Fig. 2.16

Concept of Facial Force Equilibrium Circuits

A unique force distribution pattern develops with each and every bite location. The result, a specific facial force equilibrium circuit (FFEC), is then subjected to finite analysis and strain-gauge analysis.^{15,60} In this way, the FFEC illustrates the stress and strain at each finite point of the craniofacial skeleton. The mandible according to these patterns acts as a partner to the midface in the creation of each FFEC. The craniomaxillofacial circuits to and from the upper cervical spine and other collateral areas is yet to be defined.

Finite analysis models can elegantly demonstrate patterns of stress, in both intact and in damaged craniofacial systems, to which surface fixation devices have been applied. Further study of the features of the craniofacial system, under stress and during and after healing, would refine operative techniques and further the development of newer appliances for the treatment of injuries and eventually for elective, reconstructive procedures (**Fig. 2.16**).

■ Key Points

Widespread distribution of load forces throughout the craniomaxillofacial skeleton, suspected by surface lacquer impact studies and by high-speed cinematography, is now confirmed by finite analysis. Zones of compression and tension create unique patterns (circuits) of force distribution, to and from the cranium, with full participation of thick (buttresses) and thin bone.

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3 Finesse in Buttress Restitution

■ Part 1. Peregrinations of the Past

Clinical Assessment and Indications for Repair

Clinical Presentation

The Napoleonic and the European Wars during the Second French Empire (1792 to 1815 and 1852 to 1870, respectively) revolutionized armed warfare due in great part to the introduction of mass conscription and the use of artillery.^{1,2} The injured soldiers of the day made their way after trauma by walking from the lines of confrontation to distant health stations for wound care; rarely was retrieval by horse or horse and wagon available. The less able were left to await assistance or suffer an agonizing death.³⁻⁶

Significant refinements in evacuation and triage awaited World War I, when Antoine De Page established an *Ordre de Triage*.⁶ The injured were “whisked” by motorized ambulances to dressing stations and centers of progressively more definitive care (**Fig. 3.1**).

Patients in acute distress from hemorrhage or with critical cavity wounds were taken to mobile surgical centers nearby, but others, with cranial and/or facial injuries, were evacuated to Versailles or Compegne, France (some 10 or 12 miles from the front) or to La Panne, Belgium, near the coast, collectively considered a final level of triage (**Fig. 3.2A,B**).

Some soldiers subsequently underwent reconstructive procedures at centers in metro-Paris, such as Neuilly Hospital (Lycee Pasteur), and in metro-London, at Saint Hughes College. There, patients entered the care of Morestin, Gillies, and Cushing, to name a few.⁶⁻¹⁰ These early efforts at triage of the injured and management of their wounds were utilized decades later, during care of the injured in World War II.

Operative Repair

Algorithm of Repair

Open wounds during World War I were dressed with linen at so-called dressing stations immediately behind the lines



Fig. 3.1

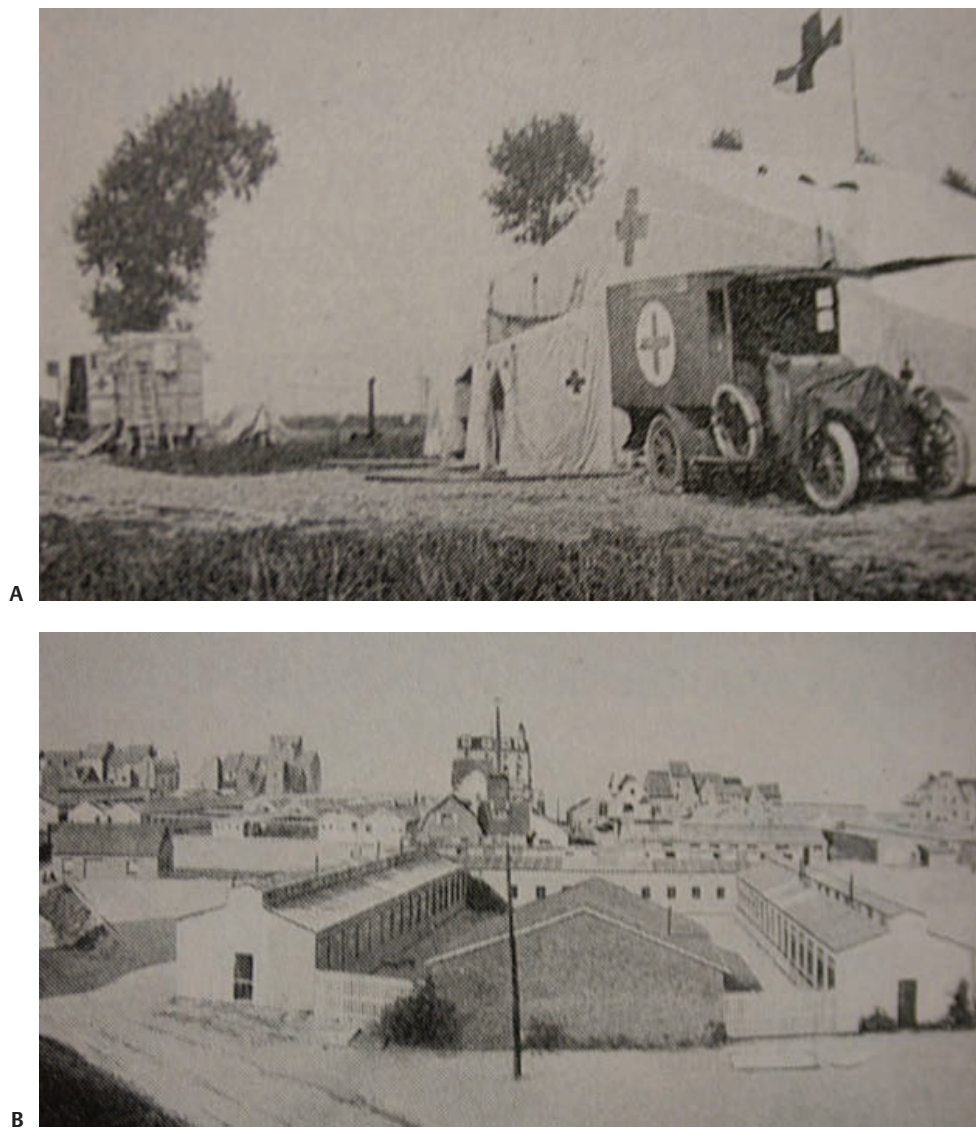


Fig. 3.2 (A, B)

of confrontation. Priority was given to those suffering acute bleeding, as they were shuttled to close-by mobile centers. Wounds of the thorax or abdomen were given “higher status” for intervention as soon as conditions permitted. Débridement of open wounds and neurosurgical care were given priority at more distant hospital centers, relatively far from the battlefield. The repair of cranial or maxillofacial fractures was deferred, pending long periods of observation while awaiting improved neurologic status^{6,11} (**Fig. 3.3**).

Incisions, Prealignment, and Stabilization

French Empire surgeons uniquely recommended proactive, incisional débridement of gunshot wounds and even early amputation of extremities (1852–1870), but their advice was

largely discounted. Doubters dominated, and, until World War I, the technique of open exploration and débridement of wounds was deemed to be inappropriate and subject to unacceptable risk.^{6,12,13} During the Great War (World War I) and World War II, the role of débridement was resurrected and, particularly in the Vietnam Conflict, reinstituted as routine at most surgical and evacuation hospitals. Copious irrigation of wounds with dilute bleach (Dakon’s solution), using a Carrel reservoir, was instituted during débridement and continued for an extended period.¹⁴

Stabilization of the trajectories of the mandible was achieved much as it had been for centuries: manipulation of bone fragments, the placement of circumdental wires about the teeth at the line of fracture, and the application of a craniofacial dressing.^{6,15} Or, more often, an articulator-

**WOUND DRESSINGS, CONTROL OF
HEMORRHAGE, AND THE
MANAGEMENT OF CAVITARY WOUNDS**



DEBRIDEMENT OF OPEN WOUNDS



NEUROSURGERY



EXTENDED PERIODS OF OBSERVATION



REPAIR OF FACIAL FRACTURES

Fig. 3.3

derived, Bean-Gunning type of oral splint was utilized,¹⁶ in lieu of circumdental wire, to stabilize the fragments of a broken lower jaw before applying a “Bertrandi,” “Barton,” or “Hamilton” dressing¹⁷ (**Fig. 3.4**).

Various dental wire loops and arch bars were devised before and during World War I. The introduction of arch bars *with lugs* in 1925 (Erich) simplified the use of intermaxillary fixation¹⁸ in lieu of external appliances and dressings, and by World War II, the bars were a standard adjunct to management of the fractured jaw. Elastic traction was used to good effect.¹⁹

After World War II, suspension wires were “dropped” from stable cranial or upper facial bone to benefit postoperative stability of midfacial fractures,²⁰ after large fragments were approximated with interosseous wires and arch bars had been applied. Local incisions in soft tissue were seen to provide direct access to stable bone and to allow minimal periosteal elevation of the facial mask, for fear of altering the blood supply of the skeleton.¹¹

Small fragments were left to align spontaneously, without wire fixation. Grafting the midfacial pillars and the walls of the orbit with bone had been conceived, but, in the main, selected only in reconstructive surgery for congenital malformations.



Fig. 3.4

Approach to Collateral Damage

During World War I, Harvey Cushing and Harvard University colleagues treated some 250 head injuries at forward hospitals, more than half with dural penetration, near Passchendaele and West Flanders, Belgium.^{9,10} Cushing's basic management was not much different from that published by Robert Barany, an Austrian Army neuro-otologist with exemplary surgical training, who recorded his recommendations in 1915, including, but not limited to, urgent wound excision, bone and soft-tissue débridement, and dural grafting (with fascia lata).^{21,22} Isolation of the central nervous system and reduced complications were assured, Barrany noted, by tight closure of dural and scalp wounds. Cushing added certain refinements to Barrany's approach: including en bloc resection of compromised brain tissue and the removal of all intracranial bullet and mortar fragments by magnets and suction, followed by a tight two-layered closure.¹⁰

The Barany-Cushing algorithm of wound management was dramatically different than the protocol of prior times, which mandated that the cranium and dura be left open for fear of suppurative encephalitis, brain abscess, or meningitis.^{6,9,23} Cushing illustrated the peregrinations of wartime intervention in 1918 in the *British Medical Journal* and in the *British Journal of Surgery*.

It was common to discard comminuted bone of the alveolar crest and palate during both world wars.²⁴ In a similar fashion, fragments of the frontal sinus were deemed to be avascular and were readily pitched. The treatment of facial fractures was not only often deferred,²⁵ postoperative

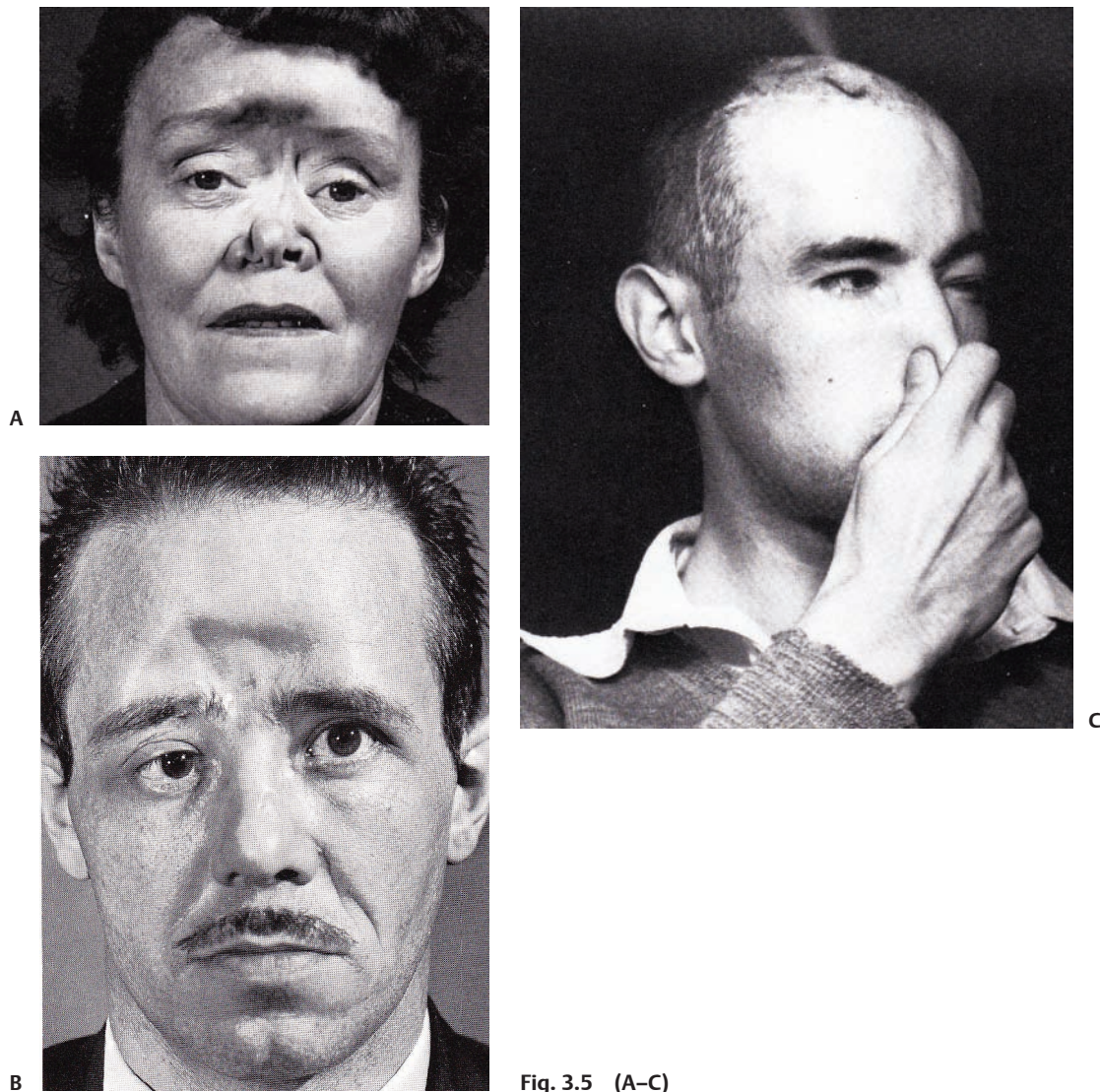


Fig. 3.5 (A–C)

deformities were commonplace.²⁶ Multiple secondary attempts were required to restore the craniofacial skeleton to normal form and function (**Fig. 3.5A,B**).

A patient that suffered fractures and discard of the central upper craniofacial skeleton is able to demonstrate a frontal sinus-and-nasoethmoid fistula by Valsalva and exhalation of cigarette smoke. The smoke is seen to escape through the anterior scalp, just above the hairline (**Fig. 3.5C**).

■ Part 2. Current Principles of Repair

The craniofacial skeleton in terms of repair can be conceptualized as *three functional and morphological units*, created by division at the Le Fort levels I and III.²⁷ The skeleton in this strategic depiction has a lower

(“occlusal”) third, an upper (“cranial”) third, and a midfacial (“maxillary”) third.

The lower “occlusal” third contains the dental arches, palatal platform, and the bases of the seven buttresses as they begin their ascent to the upper face and cranium, and thus the dentition and upper digestive tract involved in mastication, swallowing, and speech (**Fig. 3.6A**).

The upper third of the craniofacial skeleton, composing the anterior and middle cranial vault, includes the roof of the orbit and affords protection and support for the brain and the cranial nerves as they make their outward egress to supply the bone and soft-tissue mask (**Fig. 3.6B**).

The middle third of the craniofacial skeleton contains a majority of the orbital frame, the walls and floor of the orbit, and the upper face, supporting and protecting the nasal conduits, sinuses, and orbital contents. Injury to the upper third is characterized by fractures that separate the face

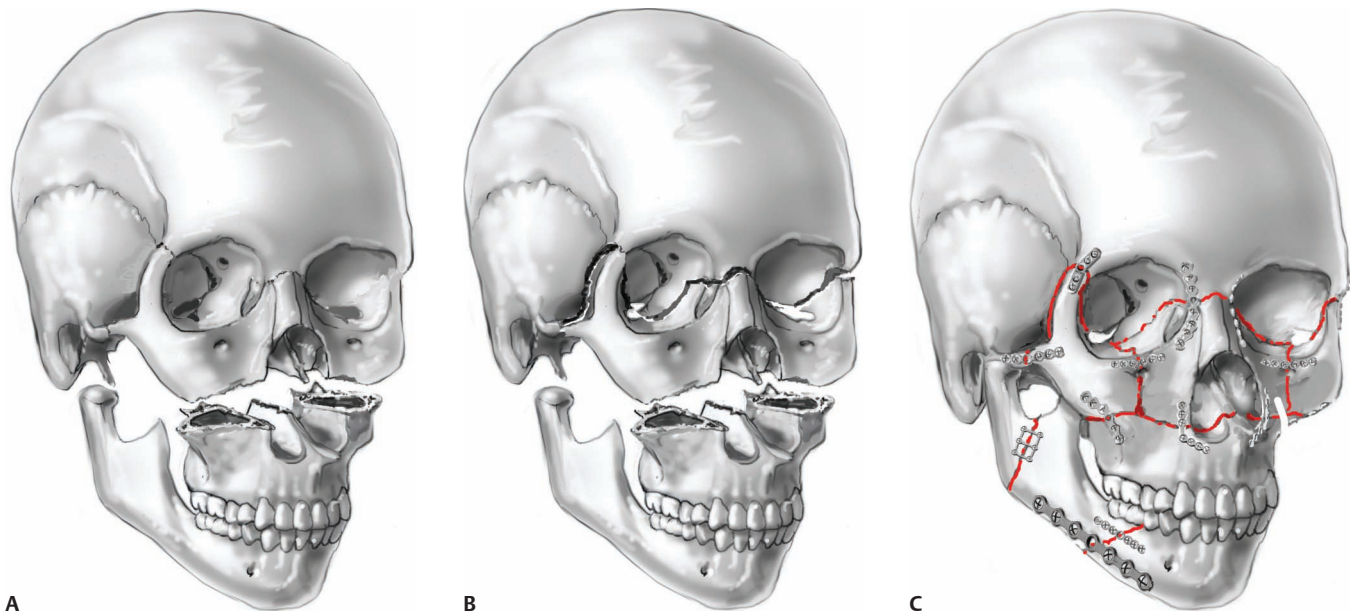


Fig. 3.6 (A–C)

from the cranium; the level III Le Fort fracture passes through the temporozygomatic and sphenozygomatic sutures, the frontomaxillary and nasofrontal sutures, the ethmoid and sphenoid sinuses, and the orbits.^{28–32}

Accurate repair of the fractured craniofacial skeleton is based on relating the palatal platform, alveolus, and lower maxilla to the mandible. The lower “occlusal” third of the face is thus the first to be restored. The repair next reestablishes the frontal sinus and frontal boss; by doing so, the anterior cranial vault is restored and isolation of the dura and cranial content assured. Third and finally, the relationships of the central and lateral upper face to the cranial vault and cranial base are reestablished, the orbital frames are reassembled, and the orbits are returned to appropriate volume. The inferior and superior maxillary zones of the craniofacial skeleton may then appropriately relate to each other^{11,31,32} (see Chapter 9) (Fig. 3.6C).

Clinical Assessment and Indications for Repair

Clinical Presentation

Immediate resuscitation and rapid retrieval of the injured dramatically improved after the early efforts of French Empire surgeon Dominique-Jean Barron Larrey and notably World War I veteran Antoine De Page.⁶ Certainly, the speed with which the injured are today whisked from the scene of injury to centers of advanced care is remarkable. Improved airway and anesthesia skills, the transient use of potent antibiotics, and rigid stabilization of comminuted bone have resulted in better outcomes.

These improvements have been reached despite a concomitant increase in the velocity of vehicles and missiles. Vehicular speeds exceeding 70 miles per hour are not uncommon. Also, rifle bullets traveling at 2500 feet per second have been supplanted by improvised explosive devices, delivering payloads at 25,000 feet per second, creating profound disruption of soft tissue and comminution of bone (Fig. 3.7).



Fig. 3.7

Sophistication in airway control and more logical strategies of fluid resuscitation and the development of trauma scores (see Chapter 6) warrant improved survival. Early intervention in cases of airway obstruction is now commonplace, beginning at the scene of injury. The development of sophisticated evacuation systems has made delivering quick-response teams by air or by surface to intervene at the scene of injury available. Airway management and protection of the spine have reached new levels of competence.

Greater emphasis has been placed today on early control of hemorrhage, attention to base deficit (acidosis), and the avoidance of persistent tissue hypoperfusion. Improved surface oxygen-monitoring technology and the infusion of thawed fresh-frozen plasma in lieu of packed red blood cells are now considered the more viable options in so-called damage-control resuscitation.³²⁻⁴⁴

Indiscriminate crystalloid fluid infusion, once dogma, has been discouraged since the millennium^{41,42} because of its harmful side effects, including induced hemodilution, hypothermia, coagulopathy, and postoperative immunological suppression.⁴¹ The renewed, preferred use of blood products, notably fresh-frozen plasma in lieu of crystalloid, followed meta-analysis of data from several institutions.

Overlapping skill sets among specialties encourage a high level of corroborative care of the injured once a tertiary center is reached. "The initial consultation after high velocity-injury can be either the moment of truth or the moment of deception"⁴⁵ (as in much reparative surgery).

Radiographic Assessment

The window of diagnosis is greatly aided today by high-resolution computerized tomography (HRCT) and three-dimensional reformatting (3-DR).⁴⁶⁻⁴⁹ The potential for survival despite widespread comminution of the entire craniofacial skeleton is now recognized, as revealed by computerized tomography, HRCT, and 3-DR. The detail of these studies is now such that a preliminary plan of operative care may be reasonably formulated before operative intervention occurs.^{11,48,49}

Short delays in acquiring detailed radiographic assessment and careful preoperative planning cause little difference in intensive care or hospital length of stay and actuarially result in a negligible difference in rates of infection and complication.⁵⁰ The brief delay in operative intervention affords the opportunity to reflectively review radiographs on numerous occasions before surgery and increases the yield of unrecognized injury.⁴⁸

Intraoperative Radiographic Assessment

HRCT during surgery (using portable units) allows assessment of the repair of the craniofacial injury in an ongoing

manner. This intraoperative modality has great promise as an adjunct to more precise reduction of fractures of the orbit and the orbitozygomatic complex. 3-DR will probably be optionally added.

General Patterns of Fracture

Patterns of injury, first identified at the turn of the preceding century when Le Fort exposed cadavers to various load forces, are now just a few of many patterns revealed by modern HRCT and 3-DR. Paradoxically, these radiographic studies also document the uniqueness of most patient injuries. So, while certain patterns of injury are apparent in each third of the craniofacial skeleton, the surgeon is aware that patients carry "an imprint specific to their individual injury."^{51,52}

Current radiographic studies provide considerable detail, such that an admix of simple patterns and extensive comminution may coexist in the same patient: one side or level may bear innocent, nondisplaced injuries, while the opposite side or a different level has been reduced to orts, with faults reaching distant, collateral areas. Anticipation of the myriad of patterns and the uniqueness of each injury improves preoperative assessment. Despite this foreknowledge, the *final* surgical formulation is deferred in several cases until broad exposure and manipulation of the fractured segments has been achieved to assess instability.⁵²

Fractures of the palate tend to occur off the midline, in thin parasagittal bone, and often exit the anterior maxilla between the most mesial teeth of the anterior segment. The split palatal shelves splay outwardly with buccal version of the palatoalveolar segments, creating untoward instability of the lower third of the face. The instability of the palatal platform has the ability to profoundly influence the occlusion of the jaws (**Fig. 3.8**).

Fractures of the mandible tend to be bilateral, with injury inflicted at the symphysis or body on one side and the angle or subcondylar neck on the other. The symphyseal fracture tends to be oblique, with telescopic overlapping of the mandibular fragments. When the angle is involved, the fault commonly begins at the inner (lingual) cortex, traverses the root socket of the third molar, and exits obliquely through the outer cortex (**Fig. 3.9**).

Fractures of the *fronto-orbital bar* (*frontal boss*) frequently involve the anterior table of the frontal sinus. Fractures may be medial, lateral, or comminuted. Fracture may include both tables of the sinus and may extend to the nearby cribriform plate and/or the periorbit (**Fig. 3.10**).

When the fracture passes *medially* through the floor, the outflow tract of the sinus, the cribriform plate, and the fovea (roof of the ethmoid sinus) are subject to comminution, dural tear, and, in time, chronic sinusitis. Alternately, when the fracture extends through the *lateral* frontal

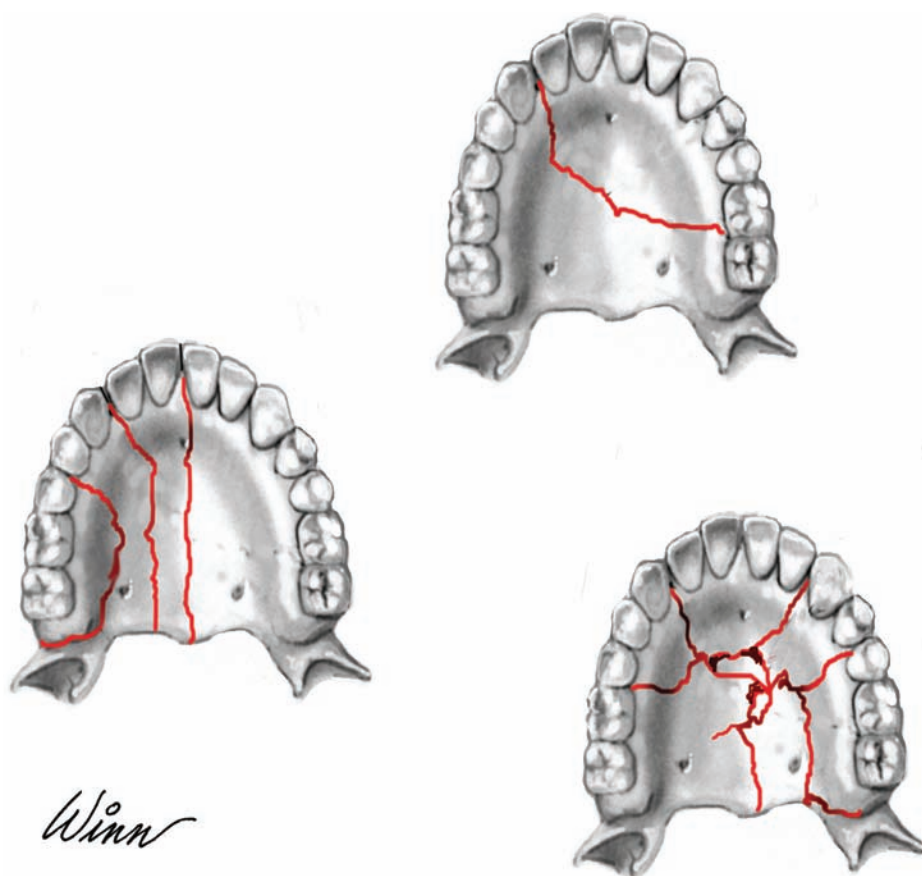


Fig. 3.8



Fig. 3.9

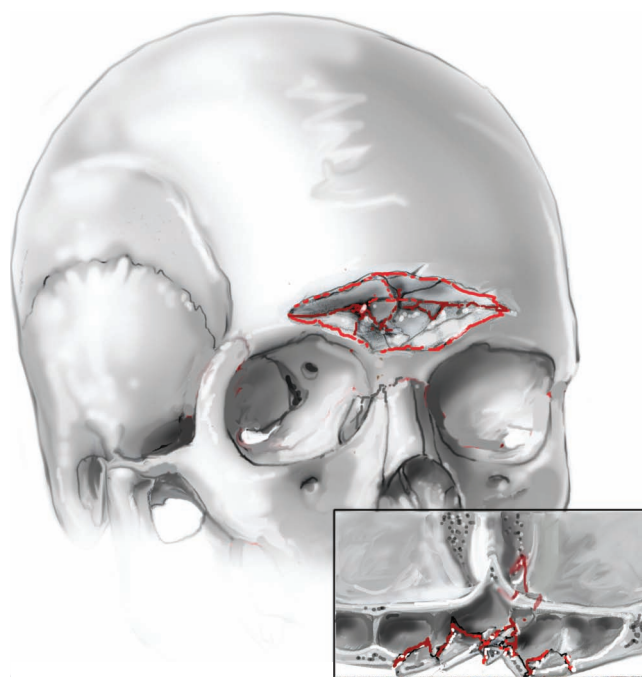


Fig. 3.10

sinus floor, involvement of the underlying orbital roof is common. The fracture may traverse thick bone of the lower portion of the frontal boss and involve the nasofrontal suture, causing separation and downward displacement of the nasal complex.

Le Fort I *maxillary fractures* progress across the maxilla (superior to the apices of the teeth) and adjoining bones, traversing the anterior buttresses shortly after they ascend from the alveolus of the palate en route to the nasofrontal suture (frontal boss) and the cranial base. In their transverse propagation, the fracture lines pass through the antrum of the maxillary sinus and the nasal cavity, just above the nasal floor. By passing through the posterior wall of the maxillary sinus and the posterior buttresses, the faults create occlusal disjunction³¹ (**Fig. 3.11A–D**).

The Le Fort II fracture elects a more oblique pathway, leaving a greater portion of the lower maxilla and the

pyriform aperture in the inferior occlusal fragment. The Le Fort II fracture separates the inferior maxilla and nose from the lateral midface and orbits by traversing the lateral midfacial buttress, the anterior face of the maxilla, and the medial midfacial buttress to reach the nasofrontal suture. Le Fort level III fractures are again relatively transverse, crossing the lateral and medial orbits and separating the cranium from the face. When the fracture lines cross the frontal boss and extend into the frontal sinus and the anterior fossa, they can be referred to as Le Fort IV fractures. The fault associated with pattern IV may pass through the sagittal maxillary (vomerine-sphenoidal) posterior buttress to reach the middle cranial fossa.^{28,31,53}

Fractures may comminute the upper aspect of the anterior medial maxillary buttresses, profoundly affecting the transverse distance between the orbits and the position of the medial canthal tendon. Behind the medial but-

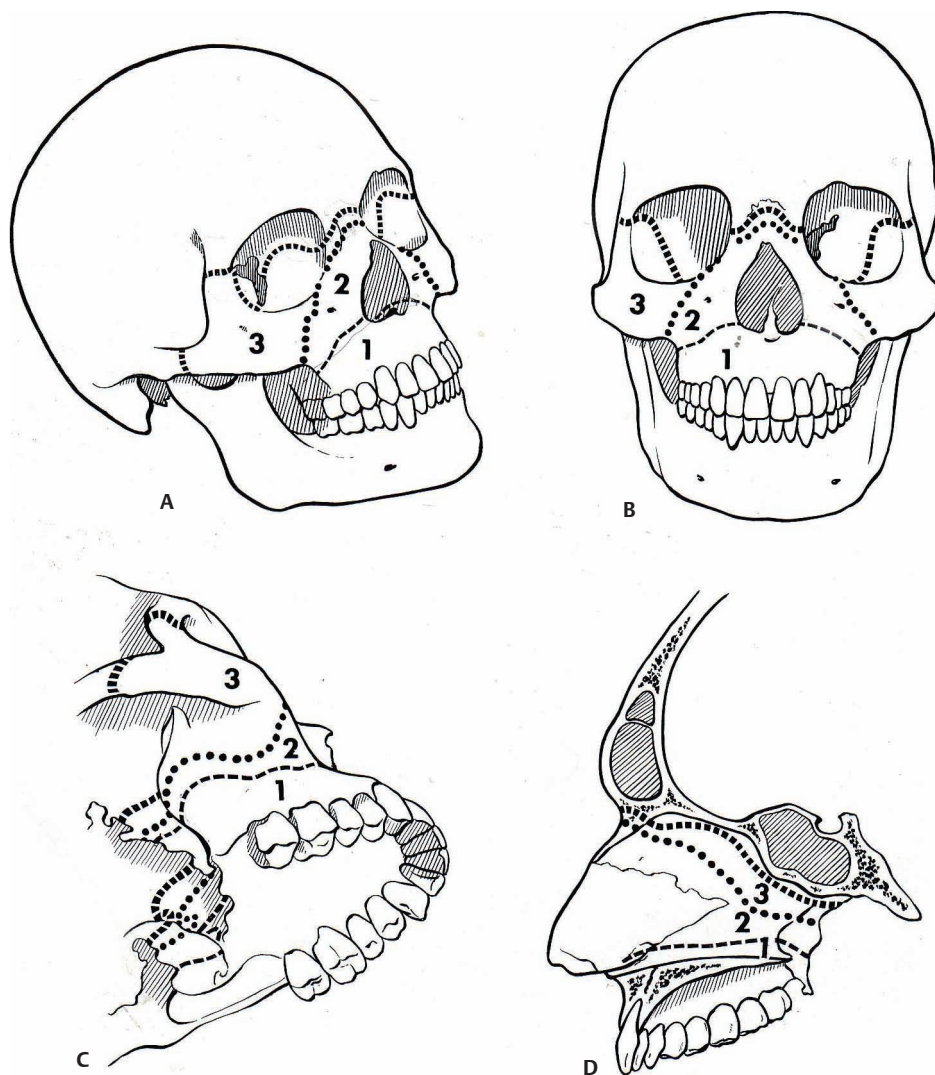


Fig. 3.11 (A–D)

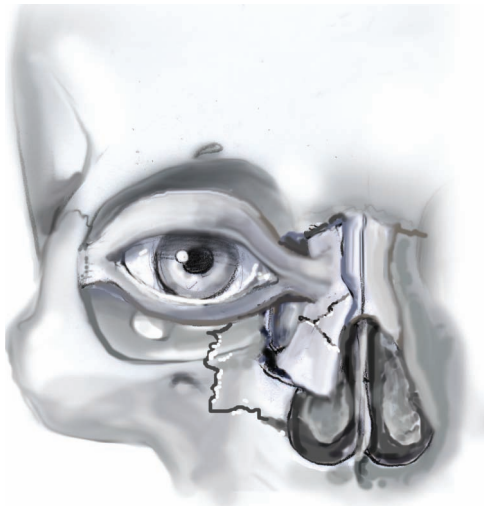


Fig. 3.12



Fig. 3.13

tresses are the lacrimal bones, the ethmoid sinuses, and the medial walls of the orbits. The medial orbital frame after nasomaxillary fractures may shift and assume a vertical position. The fracture fault may ascend to the frontal sinus and anterior fossa (**Fig. 3.12**).

The fracture pattern of the *zygoma and its arch* on HRCT is one of the more important to understand and the most often underinterpreted. The disruption is too often referred to as a “tripod” or “quadripod” fracture, neither of which give the injury due justice.⁵⁴ The fracture crosses the zygomatic arch, usually at or near the junction of the zygomatic process of the temporal bone and the temporal process of the zygomatic bone. The linearity of the zygomatic arch is disrupted, particularly when its span is comminuted. When the fracture cleaves the frontozygomatic suture, the lateral midfacial buttress, and inferior orbital rim, the zygoma is subject to rotation posteriorly, inferiorly, and medially; the zygomatic arch and the zygomatico-maxillary buttress are displaced (splayed) laterally (**Fig. 3.13**).

The fracture may profoundly reduce the orbital volume as the orbital plate of the zygoma pivots inwardly after separating from the greater wing of the sphenoid. The anterior pole of the temporal lobe of the brain, in the floor of the middle fossa, may be injured when the fracture displaces the greater wing of the sphenoid.

Fracture patterns of the *orbit* reveal *zones of vulnerability* and disruption of the *microbuttresses* that gird the roof, floor, and walls from impact, thus relatively protecting the globe and other orbital contents from injury. When reviewing radiographs, the orbit may be conveniently perceived as being *trisectional*. Though arbitrary, each section (the orbital frame, a midsection, and an apex) can then be studied for distortion and displacement (see Chapter 8).

Some orbital fractures are isolated, and, in those circumstances, the fractures usually occur in one of three locations (**Fig. 3.14**):

- The anterior medial orbital floor
- The (central aspect of the) medial orbital wall (below the level of the cribriform plate)
- The posteromedial roof

The bone in these three “areas of orbital vulnerability” is thin and contoured, supported only by microbuttresses (see Chapter 8), and in a biomechanical sense (see Chapter 2), subject to “blow-in” or “blow-out” fracture.

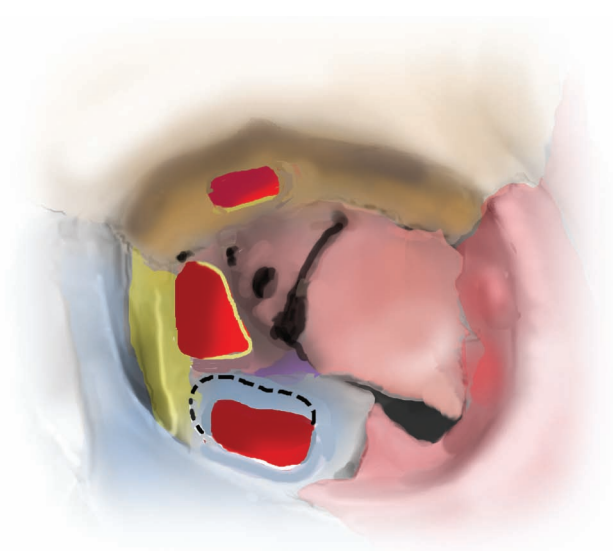


Fig. 3.14



Fig. 3.15

Photographic Documentation

A picture is worth a thousand words, it has long been said.⁵⁵ Setting aside the accuracy (or inaccuracy) of this analogy, the surgeon is today exposed to an increasing array of more complex craniomaxillofacial injury and collateral damage. Neither patient nor family may recall the sequence of the accident, and injury claims by various parties are commonplace. The reconstructive surgeon is often deposed and queried regarding cause, altered form and function, repair, and prognosis. Preoperative photographs are a significant aid in meeting these greater needs.⁵¹

Photographs that predate the injury (driver's license, family pictures) offer a pictorial frame of reference. Knowledge of *preexisting* craniofacial form, including asymmetry and even deformity, aids reconstruction after trauma.²⁸ Today's digital cameras, particularly those with a 360-degree articulating arm and dedicated flash, allow photographs before, *during*, and after surgery. The reparative effort may be reasonably documented and serve patient and surgeon alike in the event that secondary procedures are needed or legal issues are encountered (Fig. 3.15).

Operative Repair

Algorithm of Repair (Fig. 3.16)

Incisions and Prealignment

A final formulation of operative intervention in complex cases need not be chosen until surgery is well under way, when the degree of instability and injury can be more assuredly assessed.¹¹ Certainly, repair is not initiated until regional incisions (with their subsequently hidden scars), widespread periosteal elevation, and broad exposure of all fractures have been achieved (Fig. 3.17A–D).

Rigid Stabilization

Reduction of relatively innocent fractures may be achieved after minimal or no incisions. By example, a minimally

EARLY RESUSCITATION AND CONTROL OF AIRWAY AND HEMORRHAGE



NEUROSURGICAL INTERVENTION



REPAIR OF FRACTURES OF THE LOWER THIRD OF THE FACE (PALATAL PLATFORM, MANDIBLE, AND LOWER MIDFACE)



RESTORATION OR CRANIALIZATION OF THE FRONTAL SINUS



RESTORATION OF THE CENTRAL UPPER AND LATERAL UPPER FACE



RESTORATION OF THE ORBITAL FRAME AND ORBITAL AND PERIORBITAL MICROBUTTRESSES



PERIOSTEAL SUSPENSION AND SOFT-TISSUE CLOSURE

Fig. 3.16

displaced fracture of the mandible may not require an invasive procedure and will heal with minimal callous formation after the application of bonded orthodontic appliances or Erich arch bars and intermaxillary fixation for several weeks.

By other example, large-fragment nasal fractures may be reduced with gentle digital pressure and minimal instrumentation. In the latter instance, an instrument such as a Pollock-Dingman septal displacer or a Boles elevator, is positioned high in the nasal vault at the undersurface of a large, single fragment to achieve alignment. Manson refers to this maneuver as “bimanual reduction,” as the nonoperative hand is used to apply additional external guidance and gentle pressure to realign the fragment.⁵³

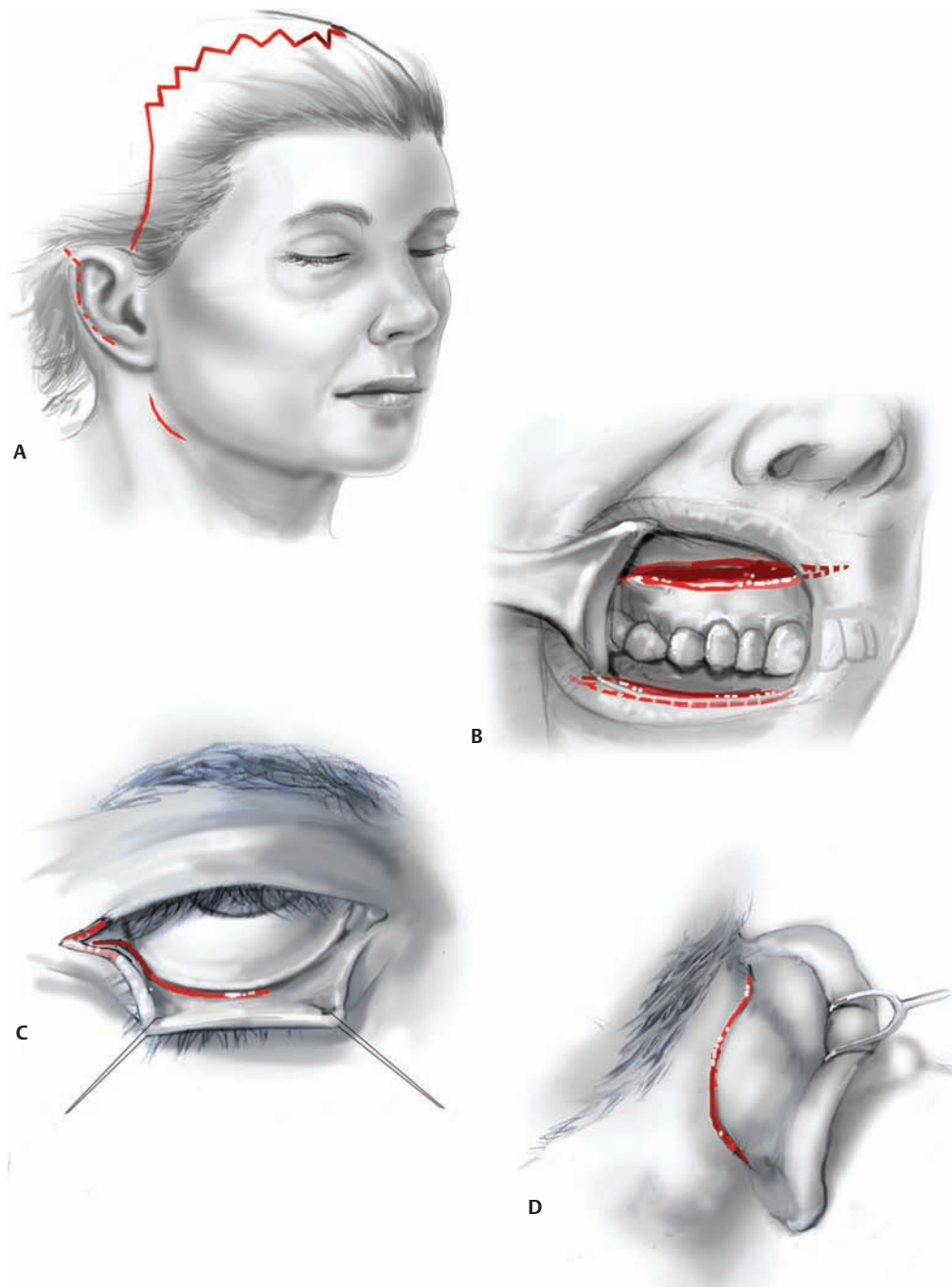


Fig. 3.17 (A–D)

By further example, a modestly displaced fracture of the zygoma or the zygomatic arch may be moved into position, in some instances, after a small local incision in the upper gingivobuccal sulcus (maxillary vestibule). A click is palpable to the nonoperative hand over the malar prominence as the zygoma assumes its prior (anatomic) location when an assistant additionally applies inward pressure along the zygomatic arch. This combined, “trimanual maneuver” rees-

tablishes the linearity of the zygomatic arch (see Chapter 8) and realigns the malar prominence. A single plate through the limited intraoral incision may establish sufficient stability of the fracture segment in these relatively modest injuries; rigid appliances (plates and screws) may even be avoided in other less dramatic circumstances.⁵⁶

Complex fractures mandate more operative intervention and broad exposure through *regional* incision(s).

Appropriate alignment is confirmed in more than one plane, and numerous plates and screws can be utilized to achieve satisfactory fixation. Relatively hidden, regional incisions are preferred over local incisions, most of which limit access and create untoward scars.

In the case of the mandible, for example, the alignment of the dentition (after intermaxillary fixation), the smoothness of the outer cortical surface, and the alignment of the inferior margin of jaw attest to the adequacy of reduction and prealignment through a regional incision (**Fig. 3.18A–C**).

Or, in the case of the zygoma, the adequacy of realignment is confirmed at three locations before fixation is applied in at least two locations (the zygomaticomaxillary buttress, the inferior orbital rim, and/or the frontozygomatic suture). In complex injuries, the linearity and rigid fixation of the zygomatic arch need also be secured.

Complex fractures that remain unstable after attempted reduction are best prealigned with 24- or 25-gauge interosseous wire in key locations before multiple plates and screws are applied. Fractures of the central and lateral upper face in general often require prealignment because of the inherent difficulty in reestablishing the components of the orbital frame (see Chapters 7 and 8) in proper, anatomic position (**Fig. 3.19**).

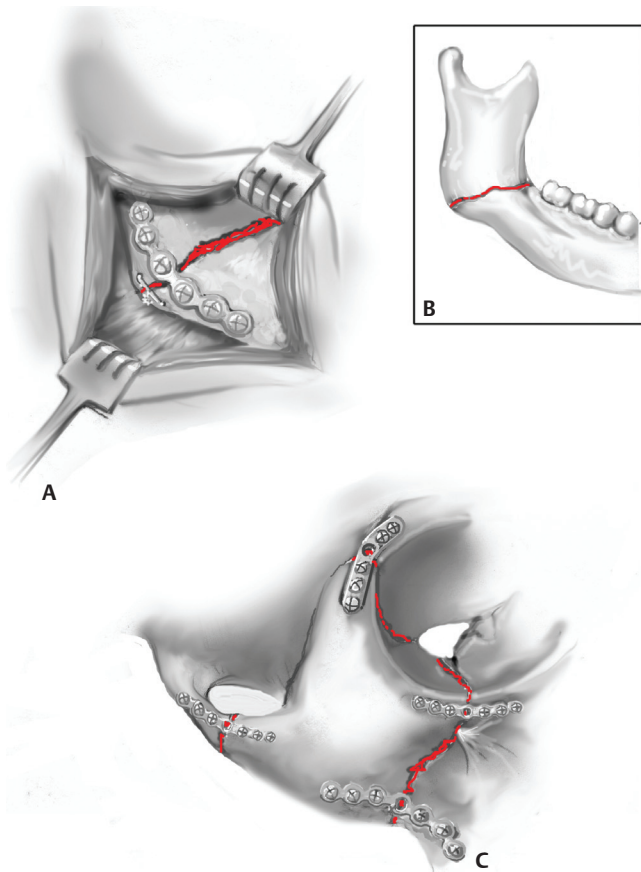


Fig. 3.18 (A–C)

Prealignment of the main structural buttress in nasomaxillary fractures (the frontal process of the maxilla) is achieved with multiple transnasal wires at several levels above and below the medial canthal ligament (see Chapter 6), for example, before plates and screws are applied to the outer surface of the bone.^{57,58}

As a final example of the routine need for prealignment, consider the fractured palate. The split and displaced palatal shelves are first brought together with pelvic, ratchet-reduction forceps; the occlusion is assured with intermaxillary posts and wire; only then are the shelves stabilized with mini-locking plates and screws in the roof of the mouth, directly through the oral cavity⁵⁹ (see Chapter 4).

Rigid Stabilization and the Concept of Buttressing

Selection and proper placement of craniofacial appliances are key to effective restoration with the goal of restoring the load-bearing capacity of the buttresses to which plates and screws are applied (see Chapter 2). The reconstituted bone resumes most compressive microtasks, but the buttress and the implant must substitute for the loss of tensile properties to the extent possible. Callous-free remodeling of bone beneath the plates and screws soon leads to an adaptation of the craniofacial bone to new loading conditions.

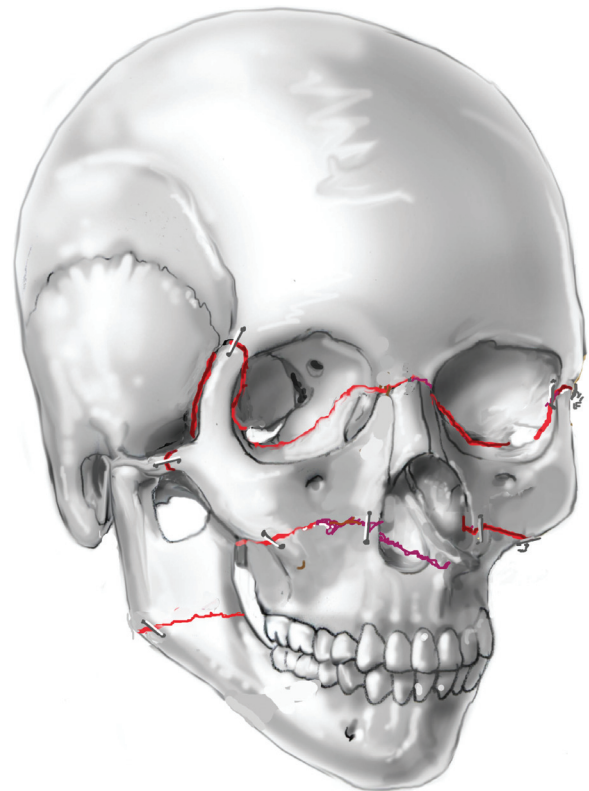


Fig. 3.19

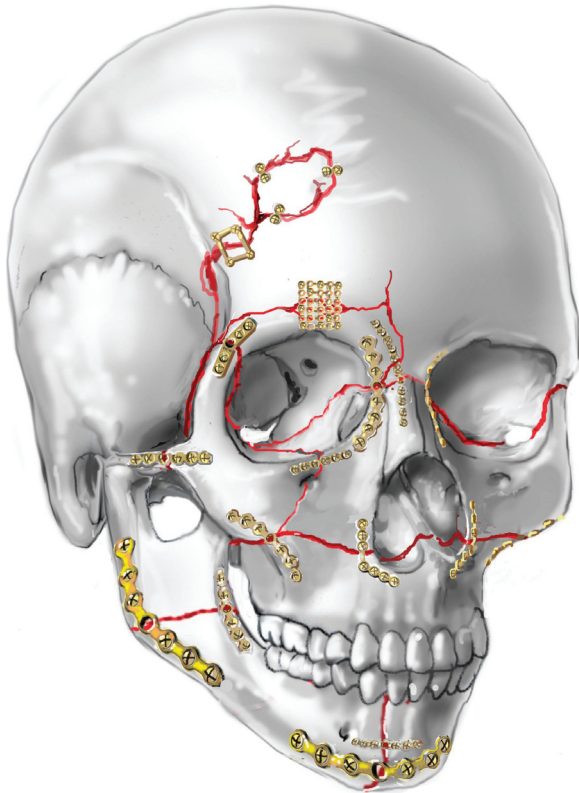


Fig. 3.20

The biomechanics of plate-and-screw design have been identified and refined.^{60–82} Favored, recent review of these features is available for further detail,^{83,84} but they are beyond the chosen scope of this text. Screws, suffice it to say, are designated according to the outer diameter of their thread. In craniomaxillofacial surgery, all screws are fully threaded and have an asymmetrical profile. A myriad of matching plates is now available for reconstruction of the fragmented skeleton (**Fig. 3.20**).

Selection of various plates and screws depends on the region of injury, on the complexity of the trauma, and on an anticipation of the forces to which the repair will be subjected. Unstable palatal shelves, for example, tend to splay outwardly in buccal rotation, unless 2.0-mm mini-*locking* plates and screws are used for fixation.⁵⁸ In the absence of very rigid fixation, persistent splaying and widening of the upper dental arch (and thus postoperative malocclusion) are a common occurrence in some 10 to 20% of patients.^{59,85} Similarly, a markedly displaced fracture of the zygoma may require 2.0-mm plates and screws to counter inward and backward torsion and rotation, particularly at the frontozygomatic suture and the lateral anterior mid-facial buttress, to conclude a sound repair. Stabilization of the medial orbital frame (in nasomaxillary/orbitoethmoid fractures) often requires 2.0-mm plates and screws also,

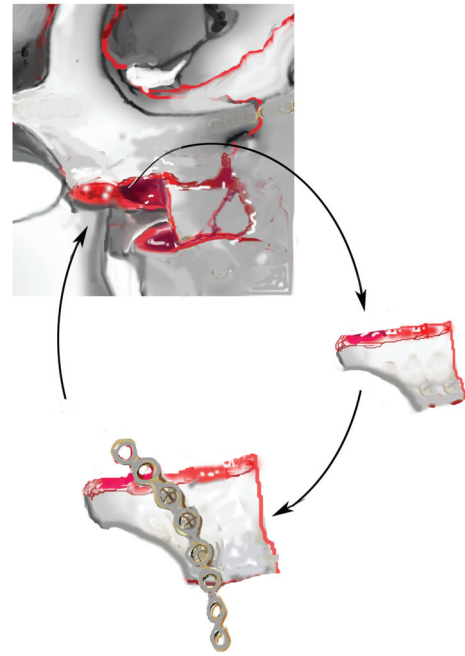


Fig. 3.21

but stabilization of the inferior orbital rim (in a zygomatic fracture) can usually be achieved using 1.3- or 1.5-mm systems. And, by final example, a locking plate at the inferior margin of the mandible and a 1.5-mm “adaptation” plate across the outer cortex offer sufficient stabilization for most complex fractures of the mandible.

Gruss, Pollock, Phillips, and Antonyshyn¹¹ suggest that rejuvenation of craniofacial *buttresses* is achieved in one of three general ways (**Fig. 3.21**):

- **Buttress stabilization:** The application of plates and screws across fracture lines of a buttress after reduction.
- **Buttress assembly:** The removal of a large fragment and its fixation to a plate with screws prior to reinsertion of the bone, plate, and screws as a composite.
- **Buttress replacement:** When comminution has been disruptive and assembly of pulverized bone will not provide sufficient form and load-bearing capacity, replacement of the buttress is indicated. The parts of bone in these unusual circumstances are discarded, and split-cranial bone grafts are used for reconstitution of the buttresses.^{86–93}

A temporoparietal site is chosen to harvest the graft. The site is first circumscribed using a cutting burr. Then, the split-cranial graft is removed with an osteotome in the diploic plane, leaving the inner cortex intact. A plate is secured to the graft with full-thickness screws (**Fig. 3.22**).



Fig. 3.22

Basic Biomechanics of Wire, Semirigid, and Rigid Fixation and Callous-Free Osteosynthesis

The biomechanics of repaired bone and changes in load-bearing capacity after surgery is beyond this text. That said, it should be appreciated that altered healing follows mobility at a fracture site. Wire tends to stretch under stress, and callous formation is then a near certainty. Plates and screws provide better stability, causing minimal callous. The reconstituted bone appears able to bear the forces routinely applied to the craniofacial skeleton^{94–114} (Fig. 3.23A–C).

Locking plate systems provide stable fixation because load forces are more evenly distributed than that provided by conventional plates and screws.¹¹⁵

Concept of Periosteal and Other Soft-Tissue Suspension

Dingman attributed periosteal suspension to Blair and his experience in the Great War¹¹⁶; review of the literature written by Blair neither confirms nor denies the Dingman affirmation. Dingman and Natvig,²⁸ in their 1964 text, *Surgery of Facial Fractures*, thus are the *published* champions of this technique in the craniofacial area. These authors emphasize the value of “reapproximation” of the periosteum, particularly the periosteum at the infraorbital rim, after the repair of zygomatic and orbital rim fractures, and at the angle or body of the mandible, after external Risdon¹¹⁷ approaches in the upper neck. Phillips and colleagues in 1991 echoed the significance of return of the periosteum over the bone (after surgery) but referred to periosteal “suspension.”¹¹⁸ They identify the need to reapproximate the periosteum after the use of eyelid incisions (used

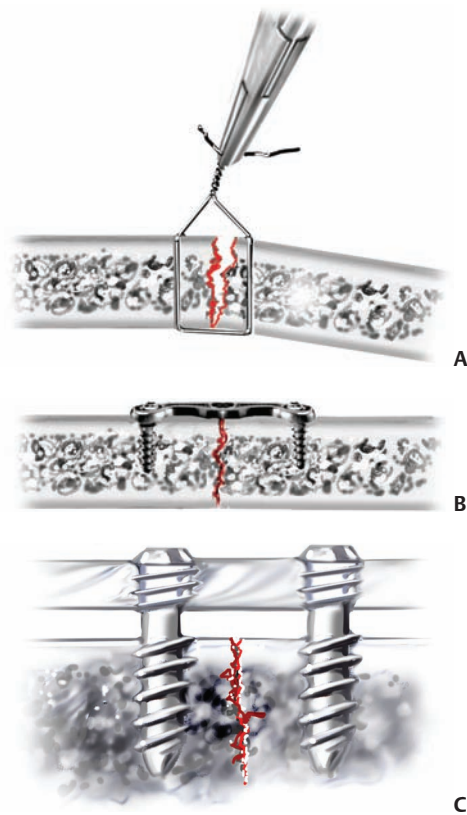


Fig. 3.23 (A–C)

to approach fractures of the midface and orbit) to prevent the anterior lamella of the lower eyelid from scarring and adhering to the inferior orbital rim after surgery¹¹⁹ (Fig. 3.24A–C).

The Blair-Dingman-Natvig-Phillips techniques of soft-tissue closure were endorsed by Gruss¹²⁰ and extended to aesthetic surgery by Hester and colleagues.¹²¹ The soft-tissue mask in the Hester cases, after the effects of aging, was strategically elevated to gain improved cosmetic result.

Approach to Collateral Damage

Premium care of complex fractures often involves multiple services, in both surgery and medicine. High-velocity impact, with subsequent dislocation, comminution, and disorder, create Picasso-like artistic drama and disharmony,¹²² much of which bear analysis and treatment.

A trauma surgeon (usually a general surgeon) often provides oversight in the early management of the patient, including controlled fluid resuscitation. With the *decreasing* role of fluid (crystalloid) infusion and the increased, *preferential* utilization of selected blood products, the role of the intensivist and blood-bank staff in initial care is increasingly recognized. Certainly in complex injuries, colleagues in emergency medicine, radiology, plastic surgery,

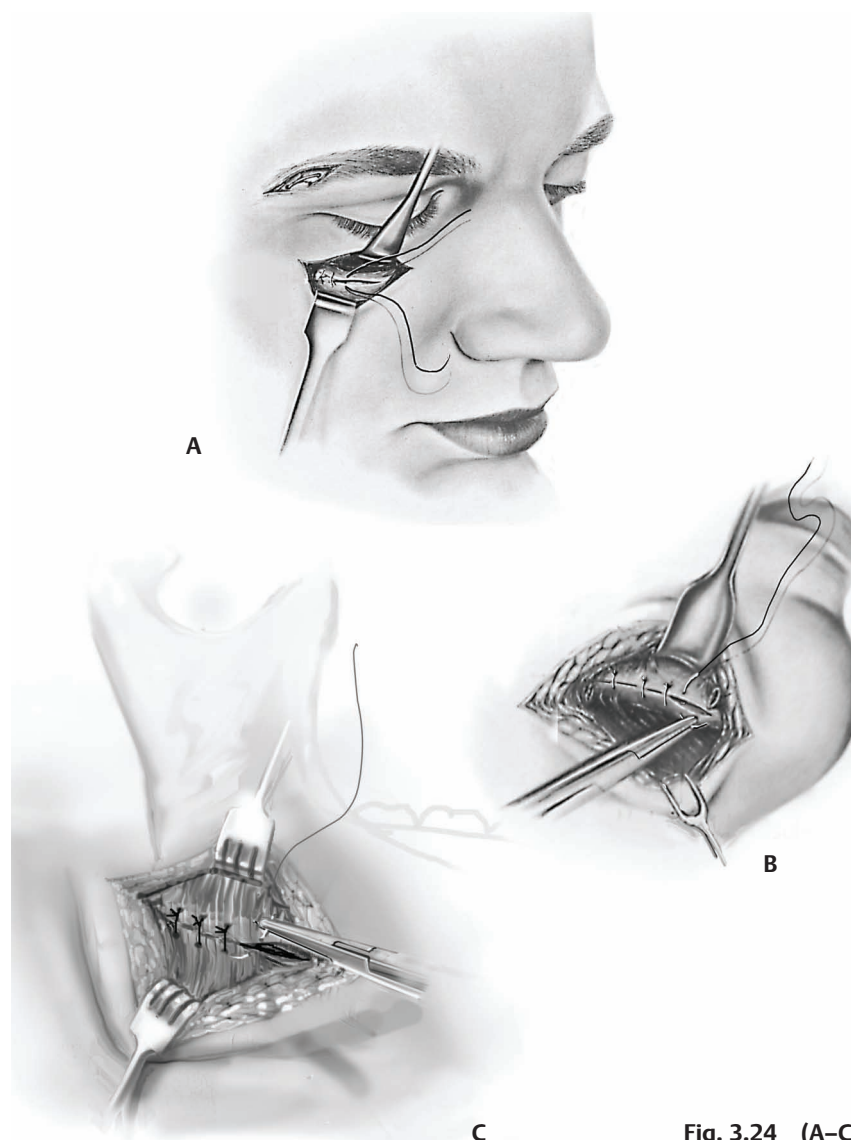


Fig. 3.24 (A–C)

oral and maxillofacial surgery, otolaryngology, ophthalmology, oculoplastic surgery, and neurosurgery often play an active, collaborative role. Because there is a high prevalence of coexisting limb and spine injuries, orthopedic surgeons become a valuable part of the team effort.

Preoperative and intraoperative consultation with anesthesiology is common. The role of the anesthesiologist may extend into the postoperative period because of lingering pain.

The general dentist, respiratory therapist, and the registered dietician play an increasing role in the perioperative care of the complexly injured patient.

Multicenter trauma center trials are under way to test the utility of acute infusion(s) of progesterone to diminish posttraumatic cerebral edema and shield brain cells from the toxicity of acute insult (traumatic brain injury) in both sexes after craniofacial trauma.

Preliminary study¹²³ suggests the possibility of lowered morbidity and mortality. The mechanism of hormonal (progesterone-induced) brain cell protection remains unknown, but early clinical analysis augurs better outcomes and portends the possibility of injectables at the scene of the injury or in emergency room departments in the not-so-distant future.

■ Key Points

Algorithms of clinical assessment and operative repair are different today than they were a mere 50 years ago. Patients increasingly survive extreme load forces that are delivered at high velocity. Polycommunion and extreme displacement and instability are common and have

triggered new concepts of buttressing, rigid fixation, and soft-tissue mask suspension. Improved outcomes have followed, even when craniomaxillofacial form has been rent asunder, splayed, and distorted.

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4 The Palatal Platform and Lower Midface

■ Part 1. Surgical Anatomy and General Considerations

The Palatal Platform

The hard palate is the platform upon which the seven craniomaxillofacial buttresses, three posterior and four anterior, reside.^{1,2} Each buttress is launched from the thicker periphery (alveolus) of the palate, then rises to engage the cranial base (**Fig. 4.1**).

The base and ascent of each buttress from the alveolus is readily apparent in the edentulous maxilla, particularly when the thin bone of the maxillary walls has been drilled away. The architecture is also demonstrated by three-dimensional reformats of high-resolution computed tomography (HRCT) (**Fig. 4.2**).

The palate is a by-product of two conjoined bones: the (palatine portion of the) maxilla and the (horizontal part of the) palatine. The palatal shelves define the dimensions of the base of the maxilla and are capped by an arch of dentition that is open posteriorly (**Figs. 4.3 and 4.4**).

The parabola-shaped alveolar process of the maxilla is more delicate than that of the mandible. The maxilla lacks a substantial cortical margin, but strength is instead conferred by the palatal shelves.³

The width and depth of the hard palate and the width and height of the mandible combine to determine the three-dimensional architecture of the lower third of the face^{2,4} (**Fig. 4.5A,B**).

The bone of the palate is thick anteriorly, but it thins progressively in its approach to the soft palate.² This anatomical feature is most apparent in sagittal and parasagittal sections.

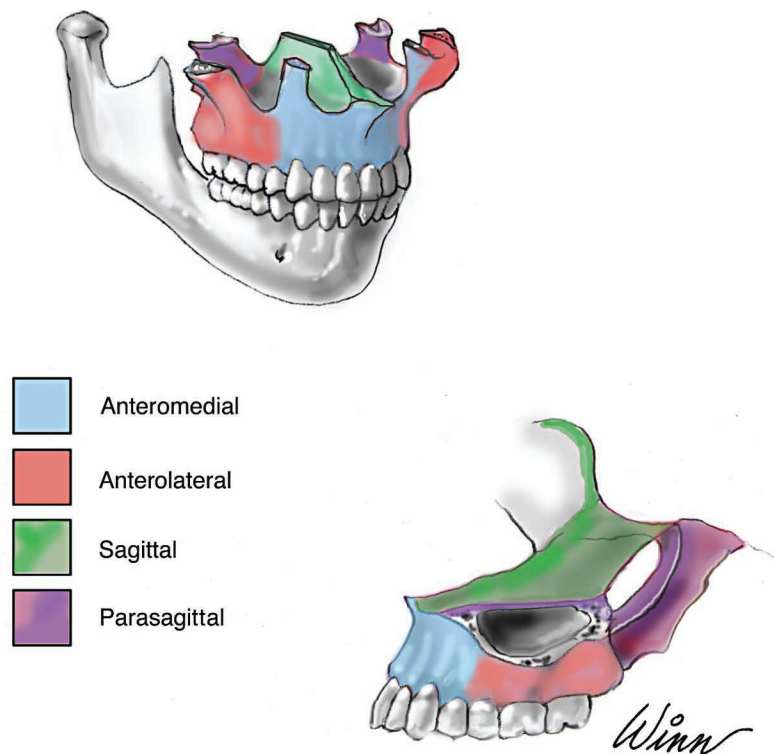


Fig. 4.1

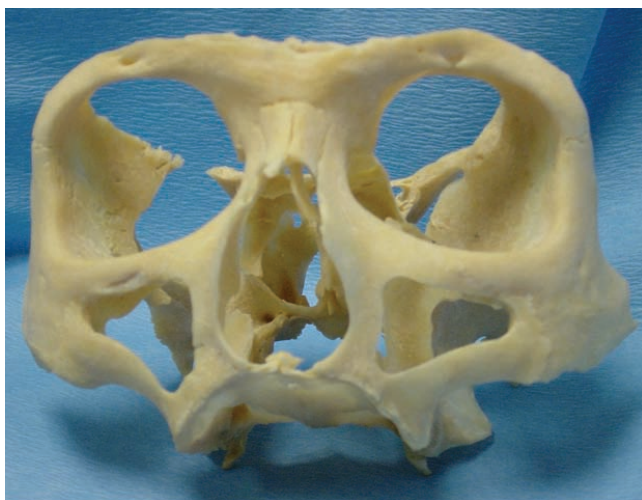


Fig. 4.2

Coronal cuts, however, reveal a different perspective: ignoring the palatal crest at the midline, the hard palate is relatively thin off-midline, but the bone thickens as the alveolus is approached. As the tooth-bearing periphery of the palate (alveolus) is reached, thicknesses of 12.0 to 14.0 mm are not uncommon.⁵⁻⁸ Screws some 4 to 5 mm in length are chosen medially to avoid penetrating the floor of the nose when repairing the palate, but screws of greater length can be chosen in the para-alveolar area without fear of penetration into the maxillary sinus (Figs. 4.6 and 4.7).

The incisive foramina are near the midline of the palate anteriorly (behind the medial incisors) and the palatine

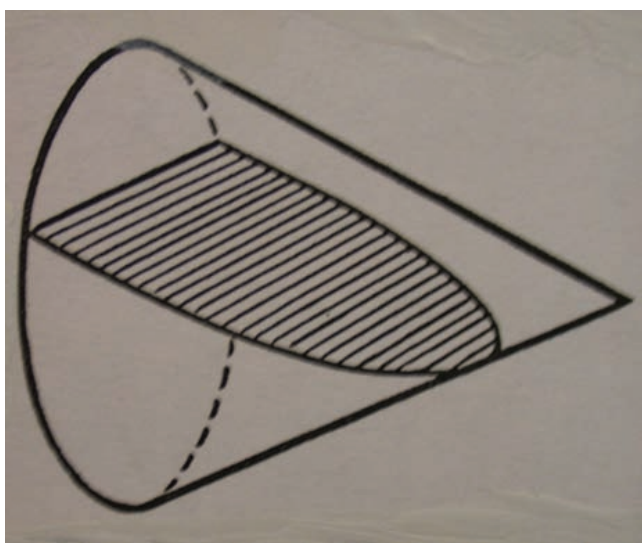


Fig. 4.4



Fig. 4.3



A



B

Fig. 4.5 (A, B)

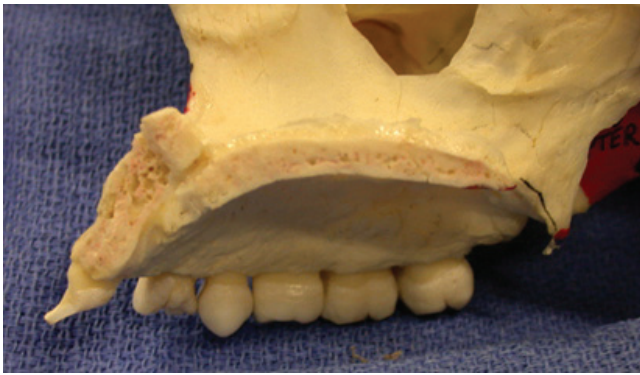


Fig. 4.6

are far off the midline posteriorly (near the distal molars). The foramina and canals within the palate are diminutive and do little to compromise the structural integrity of the palatal platform and its ability to bear impact² (Fig. 4.8).

Ossification of the median palatal suture lags behind other craniomaxillofacial sutures. The ossification is, therefore, seldom complete before the third decade,^{5,9,10} in part explaining the higher incidence of split-palatal fractures in adolescence and early adulthood.²

Ossification of the palatal suture line begins posteriorly and progresses more rapidly on the oral side of the suture than on the nasal.⁵ Histologic and microradiographic studies further reveal that the initially broad and Y-shaped palatal suture becomes increasingly tortuous with age as suture ossification advances.¹¹

The periosteum adheres more intimately to the mucous membrane of the roof of the mouth than it does to the bone of the palatal shelves. Hence, the two are referred to as *mucoperiosteum* (Figs. 4.9 and 4.10).

The maxillary alveolus is thickened both to accommodate the launch of the buttress above and to house the lateral incisor, canine, and molar dentition below. The



Fig. 4.8

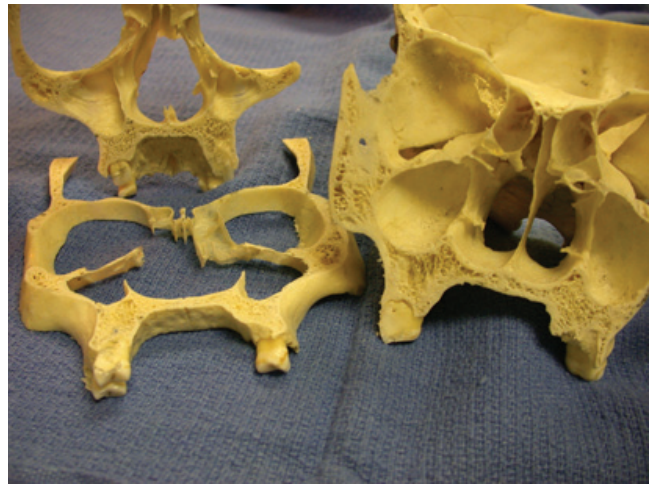


Fig. 4.7

increased density of bone to buffer this select dentition is apparent by structural analysis and digital photography.

The Craniomaxillofacial Buttresses

Seven buttresses arise from the palatal platform, as previously noted.

The Anterior Buttresses

By removing the thin, delicate midfacial bone dismissed by Le Fort,¹² Testut,¹³ and Cryer,¹ as a fragile “curtain,” the four anterior buttresses ascending from the palatal platform are

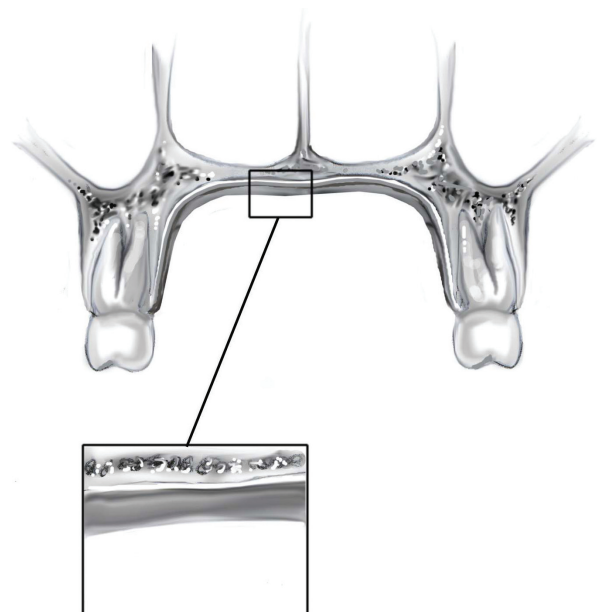


Fig. 4.9



Fig. 4.10

revealed. Two of the anterior buttresses are anteromedial, and two are anterolateral.

Each *anteromedial midfacial buttress* (nasomaxillary buttress¹⁾ begins at the anteromedial border of the palatal platform, briefly cants outwardly, then curves toward the nasal bones. The outward cant creates the tapered, lower piriform margin of the nasal vault, and the subsequent inward cant creates the upper margin of the nasal vault. The anteromedial buttress, joined by the nasal bone, ascends the sidewall of the nose, as the frontal process of the maxilla, to reach the nasofrontal suture. The buttress gives off a process laterally to form the medial portion of the inferior orbital rim. Although the anteromedial buttress is contoured, its ascent is near-vertical, as readily apparent in an oblique view.

Fractures of the four anterior buttresses tend to occur just above the palatal platform and along the piriform edge, where the bone is relatively thin. The buttress thickens progressively as the join with the nasal bones is secured and, even more superiorly, as the inferior and medial orbital frame and lacrimal bone are reached. The anteromedial buttress is substantial at the level of the nasofrontal suture. Horizontal sections through the anteromedial maxillary buttress, from inferior to superior, demonstrate the progressive depth and thickness of the buttress. This virtual change in density and shape is dramatized by removal of the nasal bones to allow unrestricted view of the anteromedial buttress (Figs. 4.11 and 4.12).

In the presence of nasoethmoid injuries of the central upper face, the nasal bones are often removed to gain

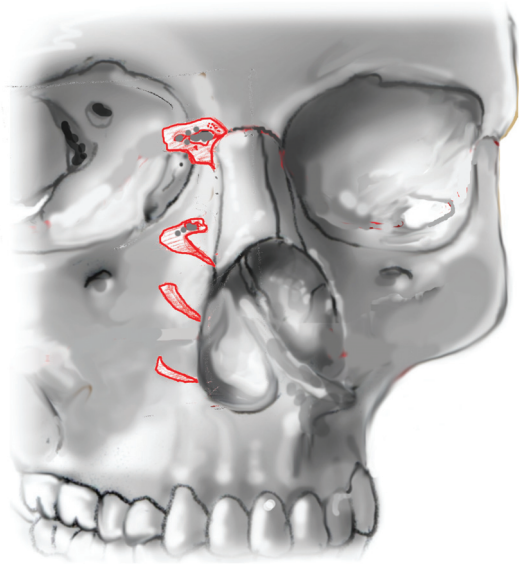


Fig. 4.11

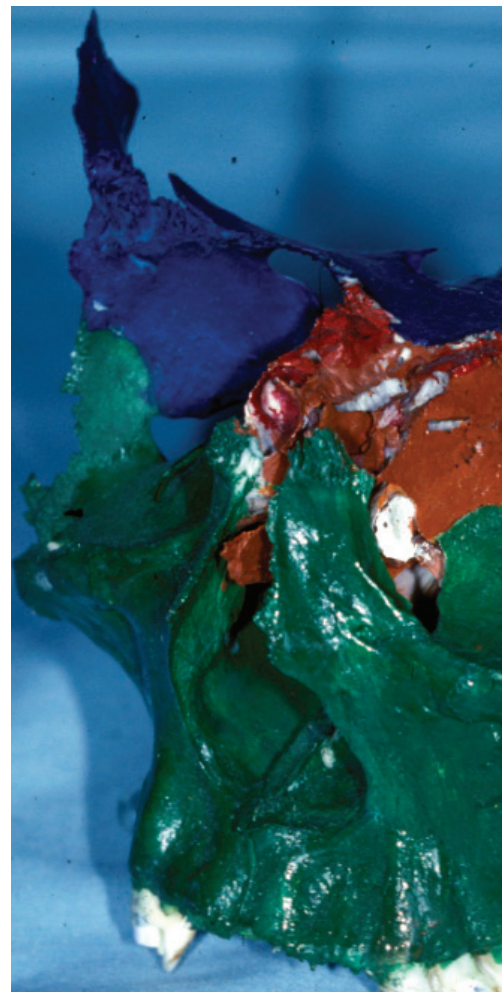


Fig. 4.12

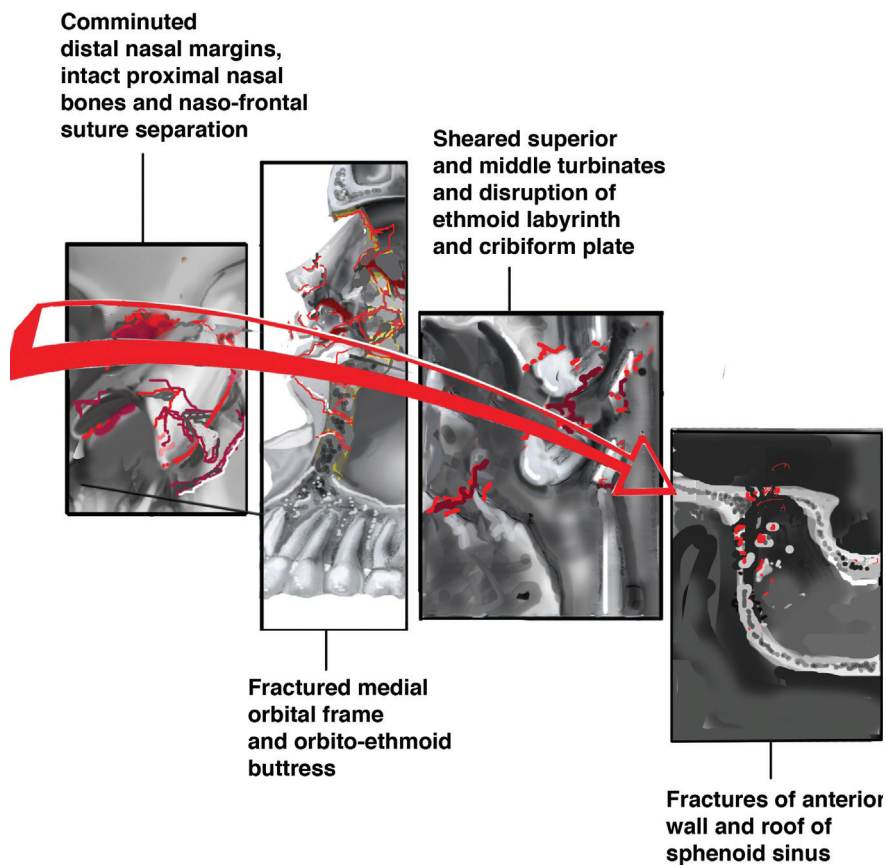


Fig. 4.13

exposure and first realign the splayed medial orbital frame with heavy wire (see Chapter 7).

Progressive thickening occurs in the nasal bones from distal to proximal and from anterior to posterior. Fractures of the nasal bones usually extend to involve the subjacent portion of one or both anteromedial buttresses. Thus, seldom is injury restricted to the nasal bones per se, particularly after high-velocity impact.

Fracture and comminution of the thicker portions of the anteromedial buttress trigger a more devastating “cascade of injury,” leading to complex nasal and septal disruption and grades of nasomaxillary and orbitoethmoid involvement (see Chapter 7). The nasal fragments and components of each buttress may be displaced inwardly by extreme impact, disrupting the underlying agger nasi cells, narrowing the nasofrontal recess (through which the frontal sinus drains), and distorting the cribriform plate. The middle ethmoid cross-struts (microbuttresses) collapse, and one or both middle turbinates are displaced inwardly as part of the nasal-nasoseptal, nasomaxillary, orbitoethmoid “cascade of injury”^{14,15} (Fig. 4.13).

The *anterolateral midfacial buttress* (zygomaticomaxillary buttress¹) begins at the anterolateral aspect of the palatal platform, over the thickened alveolus housing the

distal molars. For approximately a centimeter above the alveolus, the buttress is relatively thin and delicate, as is the case with the *anteromedial* buttresses. As it cants outwardly by some 45 to 50 degrees, in its ascent to engage the malar prominence, the anterolateral buttress progressively thickens. The body of the zygoma is an aggregate that defines the contour of the cheek and (with the zygomatic arch) establishes the projection of the upper face. The zygoma has five processes, one inframalar and four supra-malar, and is a major contributor to the lateral and inferolateral orbit and orbital frame; thus, it is structurally more orbitozygomatic than zygomaticomaxillary, as emphasized by Clark¹⁶ and Kelley and associates.¹⁷ The zygoma articulates with the zygomatic process of the frontal bone and the greater wing of the sphenoid, maxilla, and the zygomatic process of the temporal bone (see Chapter 8) (Fig. 4.14).

The Posterior Buttresses

Three *posterior midfacial buttresses* arise from the deep border of the hard palate and thus are relatively hidden from view and surgical access. One posterior buttress is in the midline (sagittal), and the other two are parasagittal (Figs. 4.15, 4.16, and 4.17).^{1,2} From a pathomechanical

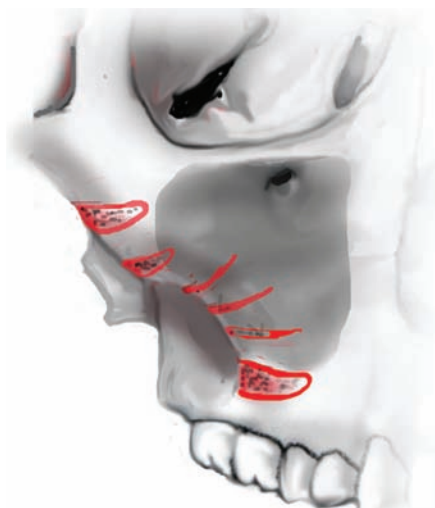
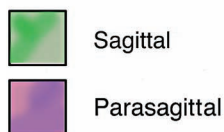
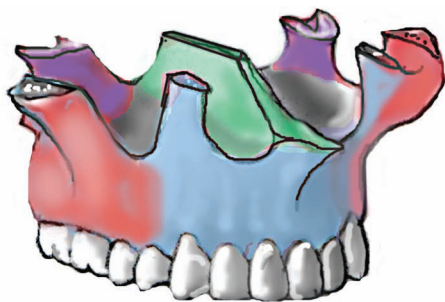


Fig. 4.14

perspective, each may be considered as outjutting to support defined areas of the cranial base.

With trauma, the three posterior buttresses often become buckled and splayed or impacted. Fractures of the posterior buttresses tend to occur inferiorly, just above the palatal platform, but access remains difficult, such that plates and screws cannot readily be applied. Restoration is dependent on disimpaction with Hayton-Williams forceps¹⁸ or their derivatives (such as the Rowe-Williams forceps or the contoured Pollock-Dingman forceps),



Winn

Fig. 4.16



Fig. 4.15

followed by repair of the palatal platform and stabilization of the *anterior midfacial* buttresses with plates and screws. In the absence of rigid fixation, healing of the posterior buttresses by callus formation typically occurs.

Each posterior midfacial buttress ascends to engage the cranial vault at an angle of some 20 to 30 degrees. The three posterior buttresses thus have a shape comparable to a hockey stick, in which the palatal platform is likened to the shaft and the buttress is analogous to the blade of the stick as it engages the cranial base (**Fig. 4.17**).

The obliquity of each posterior buttress, as it leaves the palatal platform, is particularly apparent in oblique and lateral views of the skull after the anterior buttresses and zygomatic arch have been removed (**Fig. 4.17**).

The *sagittal posterior buttress* (vomero-sphenoidal-frontal buttress^{1,2}) is launched from the palatal midline by a thick, keel-like structure, the vomer. The buttress passes upward beyond the sphenoid, ending in a terminal strut at the posterior base of the frontal sinus (the *frontal ridge*) (**Figs. 4.16** [bottom panel] and **4.18**).



Fig. 4.17



Fig. 4.18

After this lengthy course, the *sagittal buttress* becomes the longest conduit linking palate and cranium. No nerves or vessels penetrate its structure; it thus is “foramen-free” in its oblique ascent to the sphenoid and the base of the frontal ridge.

The oblique ascent of each *sagittal* posterior buttress is also evident when the skull is cut off midline through the floor of the nasal vault. The keel-like vomer is seen to be thickened throughout its ascent, unlike the nearby paper-thin, *ethmoid plate* that ascends in the midline to engage the *cribriform plate* (Fig. 4.19).

The two remaining posterior buttresses are *parasagittal*. They arise from the deep margin of the palatal platform, some 2.0 cm off the midline, and are largely uncovered by drilling away the four anterior buttresses and the thin walls of the maxillary sinus.

Each of the two *parasagittal* buttresses (pterygo-maxillary-sphenoid buttresses¹) reaches the deep border of the sphenoid sinus, where the body and wings of the sphenoid intersect (Fig. 4.20).



Fig. 4.20



Fig. 4.19

Relatively hidden from view, on the *backside* of each parasagittal outjutting, are six “foramina.” From above, in *descending* order, the conduits are the outlet of the optic canal, superior orbital fissure, rotundum foramen, pterygoid canal, pharyngeal canal, and pterygopalatine foramen (Fig. 4.21).

Light illumination and art dramatize the location of each conduit. They are clustered proximally, as depicted. The proximal location of the foraminal cluster protects their contents and the cranial base, in the event that the lower portion of the parasagittal posterior buttress gives way to the impact of load forces.

Each *parasagittal buttress* is laminated, and the components (by convention) are referred to as *laminations*, rather than cortices (as they are in the mandible and cranial vault). The laminations serve to reinforce and broaden the buttress

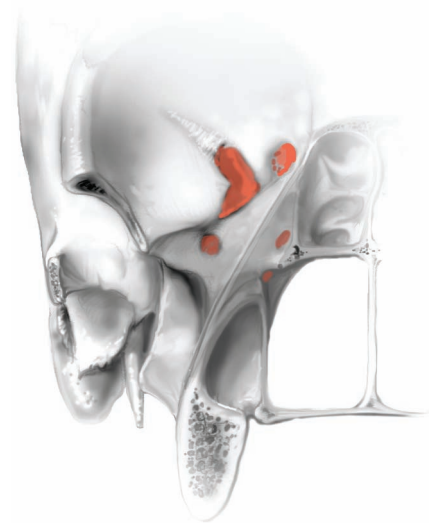


Fig. 4.21



Fig. 4.22

structure, such that fractures tend to occur just after the buttresses arise from the palate, rather than proximally at the cranial base, where the foramina are clustered and their contents are more vulnerable to injury.

The *inner lamination*, on the medial surface of each parasagittal buttress, ascends from the palate and passes through the pyramidal process of the palatine bone, to be housed proximally in the vaginal process of the body of the sphenoid.

The *outer lamination*, on the lateral surface of the buttress, ascends from the palate as the lateral pterygoid plate and joins the greater wing of the sphenoid and the lateral wall of the sphenoid sinus (Fig. 4.22).

In describing fractures of the lateral pterygoid plates, radiographic reports may understate the extent of injury. Fractures of the parasagittal buttress and its laminations, more often than not, are associated with comminution of the thin posterior and posterolateral wall.

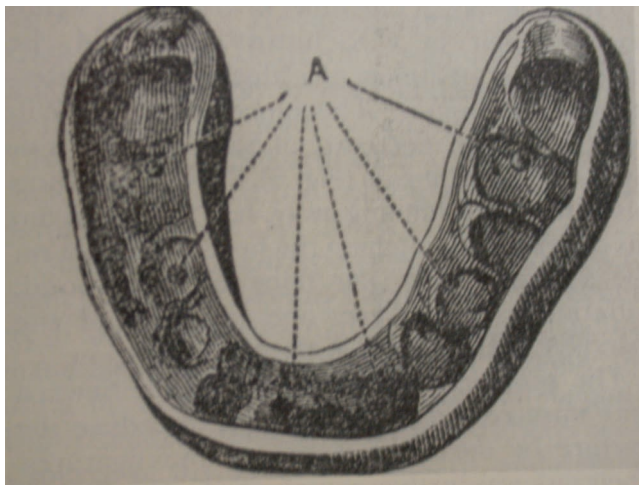
The floor and lateral walls of the sphenoid sinus (body) are thickened and create a plate-like platform for the receipt of the (sagittal and parasagittal) posterior buttresses of the midface as they converge upon the cranial base.

■ Part 2. Operative Technique and Exemplary Repair

The repair of palatal fractures is today quite different than that chosen several decades ago.^{1,2,19} During World Wars I and II, for example, the fractured dentoalveolar segment in the presence of palatal or midfacial comminution was deemed to be irreparably damaged and inherently unstable; the severely comminuted segment was thus summarily dissected out and discarded.²⁰

After the wars, attempts to harness palatal instability after fracture were made. Intraoral splints, arch bars, Kirschner wires, a palatal bar, or transpalatal wires were used with some success (Figs. 4.23A,B and 4.24A,B).^{19,21–26} Improved fixation followed the use of small, straight or “boutique X, Y, or box” plates, placed by way of *incisions* or *lacerations* in the roof of the mouth^{4,27–29} and elevation of the mucoperiosteum (Fig. 4.25). Denny deemed it proper to undertake extensive mucoperiosteal elevation and a U-shaped flap to expose the palatal fracture.³⁰

Results were mixed using these earlier techniques, because postoperatively they do not provide very rigid fixation and allow malrotation and disinclination of the palatoalveolar segments. The use of straight and boutique designer plates allow a similar fate, and a large number of cases suffer malocclusion after surgery, including crossbite.^{27,31} Although the resulting malocclusion often responds to orthodontic adjustment, surgeons have sought to achieve better outcomes.²



A



B

Fig. 4.23 (A, B)

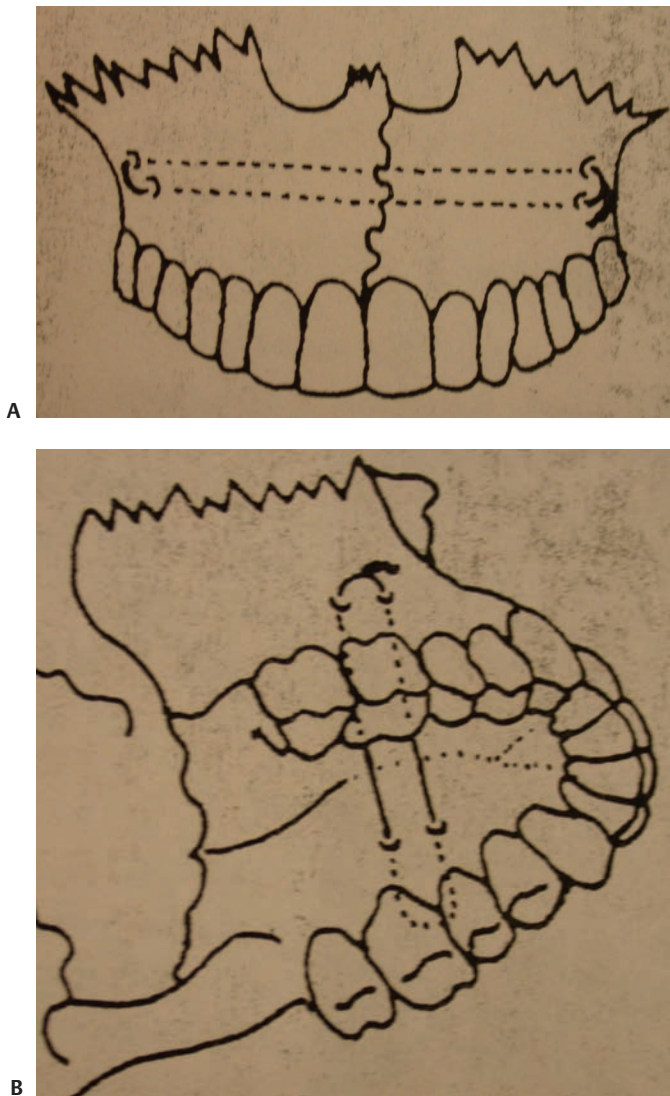


Fig. 4.24 (A, B)

Preoperative Assessment and Indications for Repair

Clinical Presentation

Injuries of the upper or lower lip, or in some cases both lips, may herald the presence of dental trauma (such as subluxation or luxation of an incisor) or an alveolar or palatal fracture. The laceration(s) often “mark” the location of the exit of the palatal fracture through the anterior face of the maxilla (**Fig. 4.26A**).

A *lip-dental-maxillary-palatal cascade of injury* is created by the impact (**Fig. 4.26B**).

Fractures that sagittally divide the palate, the maxillary alveoli, and the midfacial buttresses are a notable challenge to the surgeon because the palatal shelves are free to rotate outwardly and upwardly when the palate is split and the midfacial buttresses are fragmented. *Splaying of the palate, buccal version (outward rotation) of the pala-*

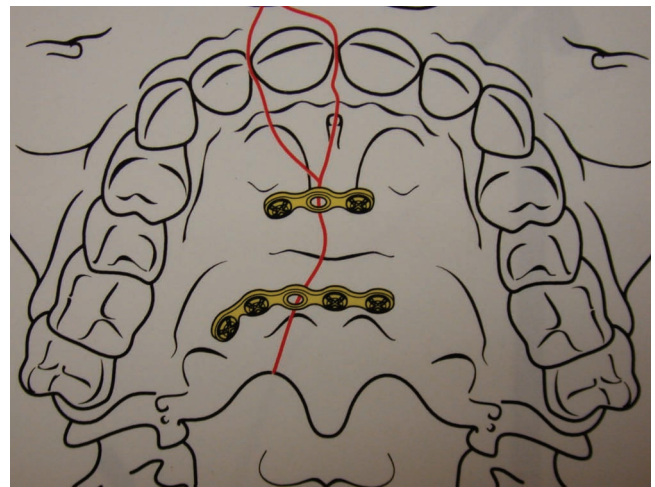


Fig. 4.25

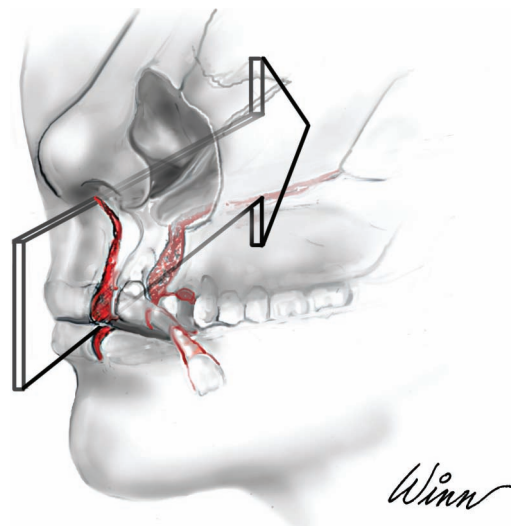


Fig. 4.26 (A, B)

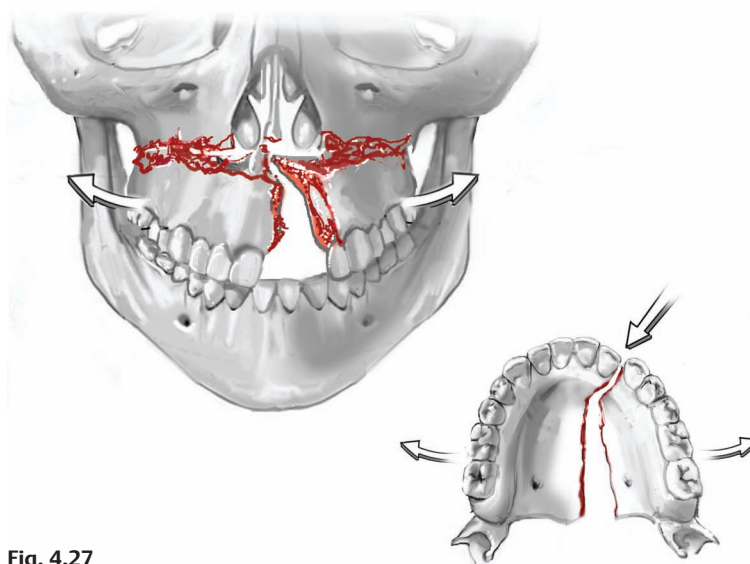


Fig. 4.27

to alveolar segments, and instability of the lower third of the face create a common clinical triad in patients with fractures of the palate.^{2,4,27}

Fractures of the palate are often part of a more extensive midfacial comminution^{12,32,33} and notably characteristic of panocraniomaxillofacial fractures (see Chapter 9). Occlusal aberrations, such as crossbite and underjet, are common (Fig. 4.27).

Bruising in the gingivobuccal sulcus (upper vestibule) may be noted, and tenderness in the sulcus and in the roof of the mouth is elicited with palpation. Midfacial instability is typically evident upon examination.

When the fracture of the buttresses is immediately superior to the palatal platform, the dental arch is mobile but the nose and periorbit are not. As fracture lines occur at increasingly higher levels, greater mobility of the upper face is noted with bimanual examination. This “bimanual maneuver” is elicited by grasping the upper, anterior dental arch with one hand and palpating the midface with the other (Fig. 4.28).

Radiographic Assessment

Radiographic studies, notably HRCT scans with three-dimensional reformatting, have provoked several classifications of fractures of the palate in past decades.^{27–29,32} A simplification of the classification suggested by Hendrickson and colleagues²⁷ is an effective aid to understanding the patterns of fracture, the categories of the injury, and plans for operative intervention² (Fig. 4.29A–C):

- Sagittal
- Parasagittal, para-alveolar (anterior, anterolateral, posterolateral)
- Transverse (or oblique)
- Comminuted

HRCT, particularly three-dimensional reformats, readily reveals the four anterior craniomaxillofacial buttresses. Most studies also reveal injuries of the three posterior midfacial buttresses, and radiographic reports tend to emphasize the deviations of the vomer and disruption of the laminations of the pterygoid plates when present.

Studies by Le Fort¹² at the turn of the 20th century using cadavers recognized three tiers of comminution:

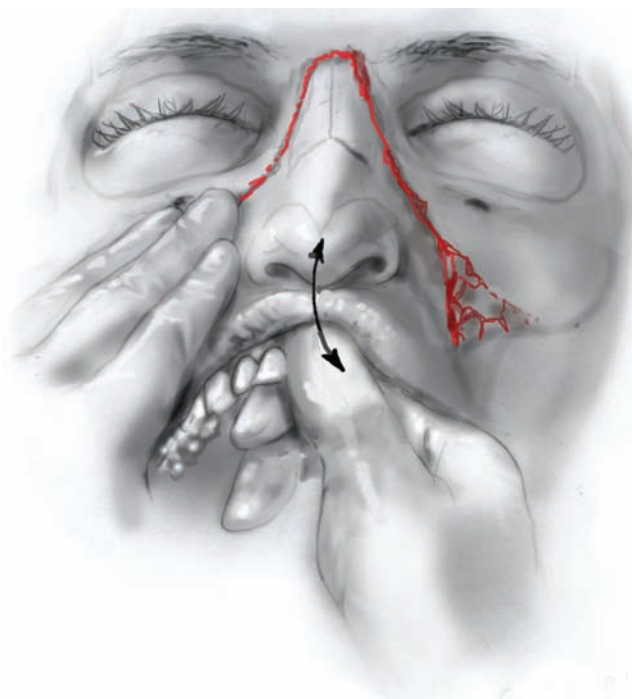


Fig. 4.28

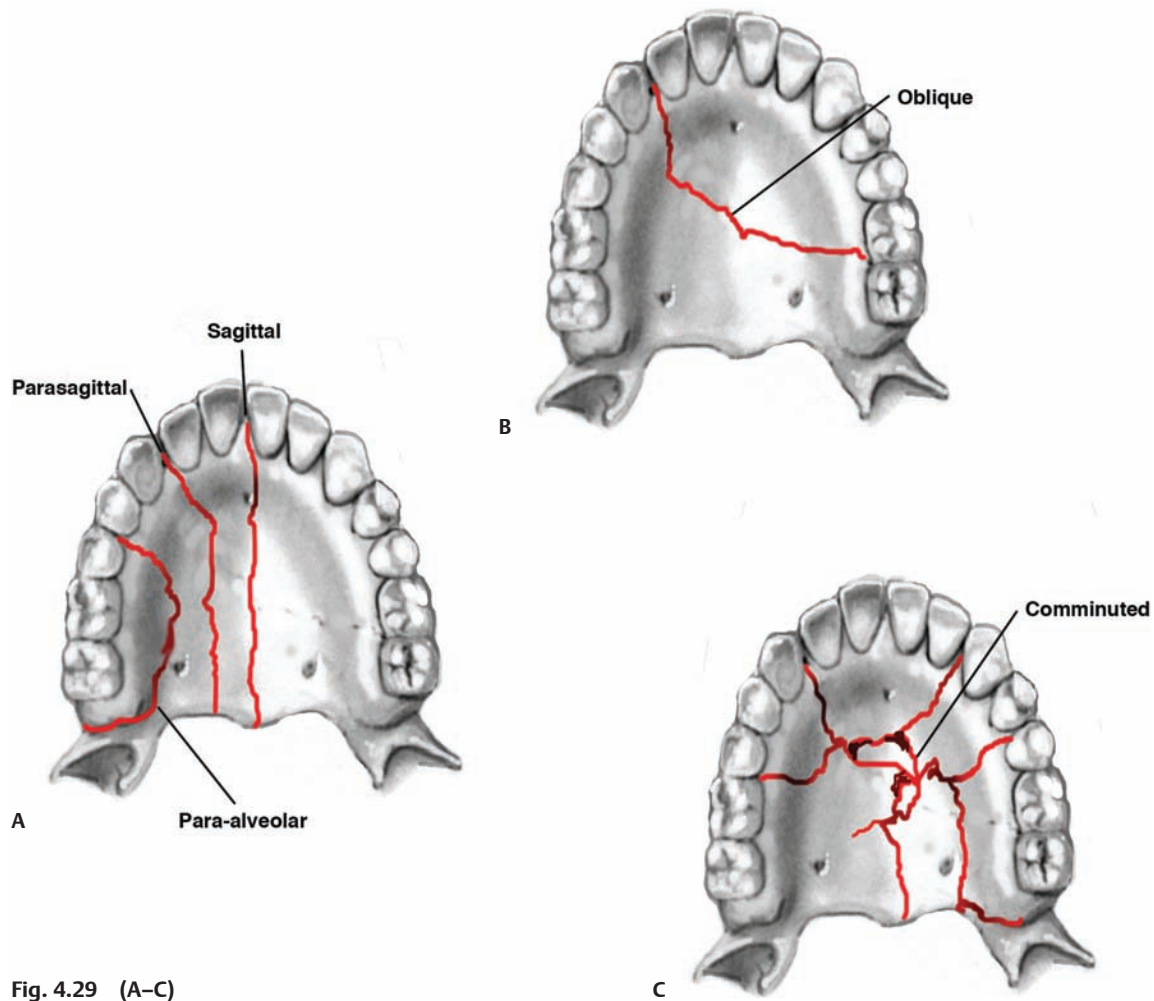


Fig. 4.29 (A–C)

Le Fort I, II, and III. Several levels of comminution may coexist. Clearly, the greater the extent of injury, the greater the torsion, distortion, and skeletal instability. The higher the Le Fort level of comminution, the greater the chance of bilateral periorbital ecchymosis (Fig. 4.30A–D).

Operative Repair of the Palate and Lower Midfacial Buttresses

Algorithm of Palatal Repair

The tendency toward rotation and disinclination (splaying) of fractured palatal shelves is controlled by prealignment and the extreme rigidity provided by transpalatal, mini-locking plates and screws. The screws are inserted directly by way of the oral cavity. The restored width and depth of the palatal platform allows the surgeon to avoid the potential bias of intraoral splints,³¹ transpalatal wires, and non-locking plates and screws.² The palate is considered the first site of repair in most pancraniofacial cases (see

Chapter 9). If there is no palatal fracture, the mandible is repaired, then other craniofacial structures (Fig. 4.31).

The goal of repair is to restore the palatal shelves as a major load-bearing platform. Stress of mastication may then be distributed to the midface and more distant regions of the craniomaxillofacial skeleton and cervical spine.

Algorithm of Midfacial Buttress Repair

Fractures of the anterior buttresses are exposed quickly through the upper gingivobuccal sulcus (maxillary vestibule). The posterior buttresses are disimpacted with forceps and allowed to heal without fixation, but the anterior buttresses are reconstituted with plates and screws (Fig. 4.32).

Surgery restores the anterior buttresses as load-bearing pathways and the maxillary sinus as a mucus-producing reservoir. The “birth-lining” (mucosa) of the maxillary sinus is preserved. Débridement is limited to suction and irrigation with the presumption that flow into the antechamber (through the sinus ostium) will resume following surgery.

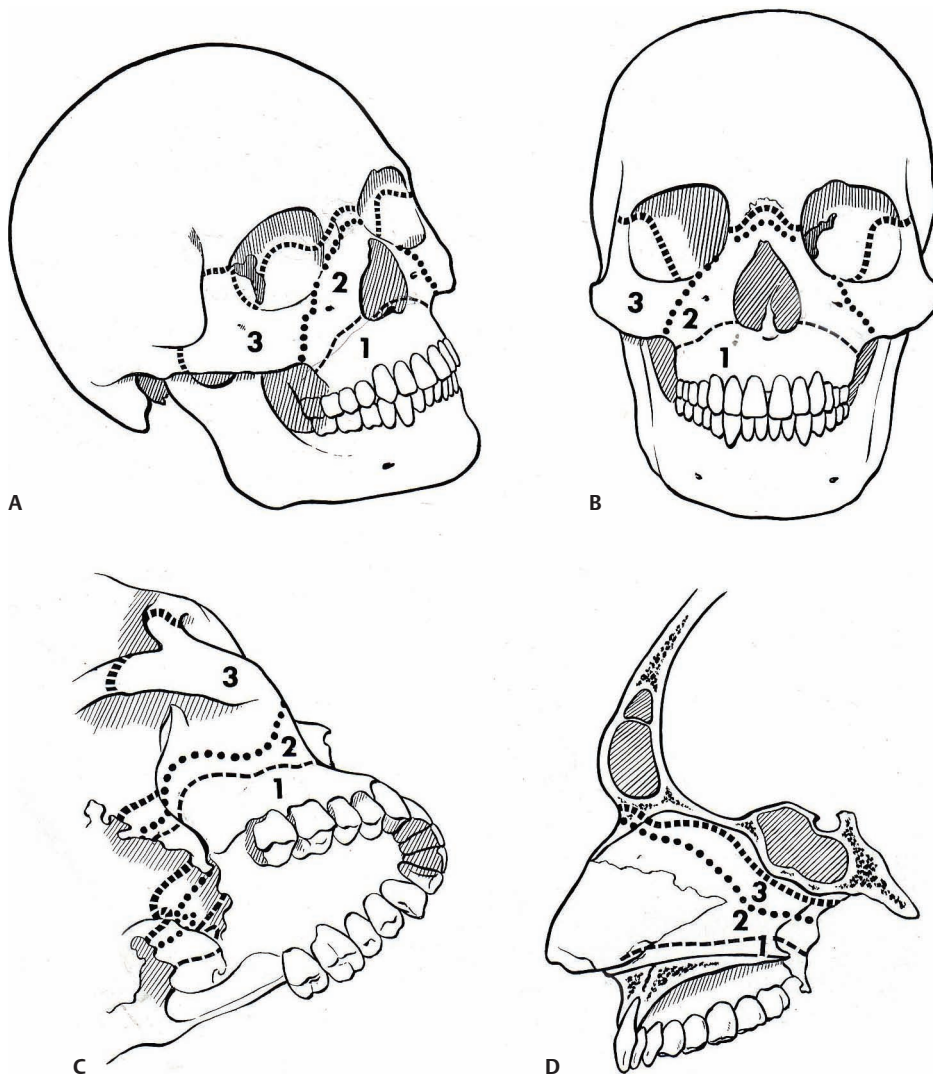


Fig. 4.30 (A-D)

Gingivobuccal Incision and Prealignment

Proper execution of the incision in the upper gingivobuccal sulcus (maxillary vestibule) is paramount. Goelet retractors are first used to retract and protect the upper and lower lips. The incision is made with an electrocautery and initially cants upward, then is directed inward, perpendicular to the (anticipated) surface of the bone. In this way, a generous cuff of soft tissue is preserved to facilitate closure (**Fig. 4.33**).

Adequate eversion of the gingival margins is achieved with a running, locking *horizontal* mattress suture, using 3-0 resorbable suture on an X-1 (half-circle) needle. Because patients often traumatize the sulcus wound during the period of healing with a toothbrush or the tongue, the running, locking horizontal mattress suture may unravel, and the closure should be additionally secured by two or three interrupted *vertical* mattress sutures.

Prealignment of the palatal shelves is a key, two-step process. First, the fracture line at the sill of the nasal vault

(piriform) or other exit site on the face of the maxilla is exposed through an upper gingivobuccal incision. A large, ratcheted, pelvic orthopedic reduction clamp is then applied across the dental arch to reduce the splayed palatal shelves. The clamp may be jostled and rocked to align the shelves in proper position as the ratchet is slowly advanced. The segments can be seen to move mesially (by way of the gingivobuccal incision) as the ratchet is progressively engaged² (**Fig. 4.34A,B**).

The clamp is applied in the area of the molars; a second ratchet clamp may be applied in the area of the premolars (**Fig. 4.34C**).

Intermaxillary (IMF) posts are inserted on each side of the exit fracture line, and wire passing *horizontally* to connect the posts is progressively tightened. The fault is progressively reduced as the ratchet(s) and the wire connecting the posts are tightened; a Corwin wire twister is used to twist the wire evenly, avoiding undue torque. Together, two ratchet clamps and the wired IMF posts apply

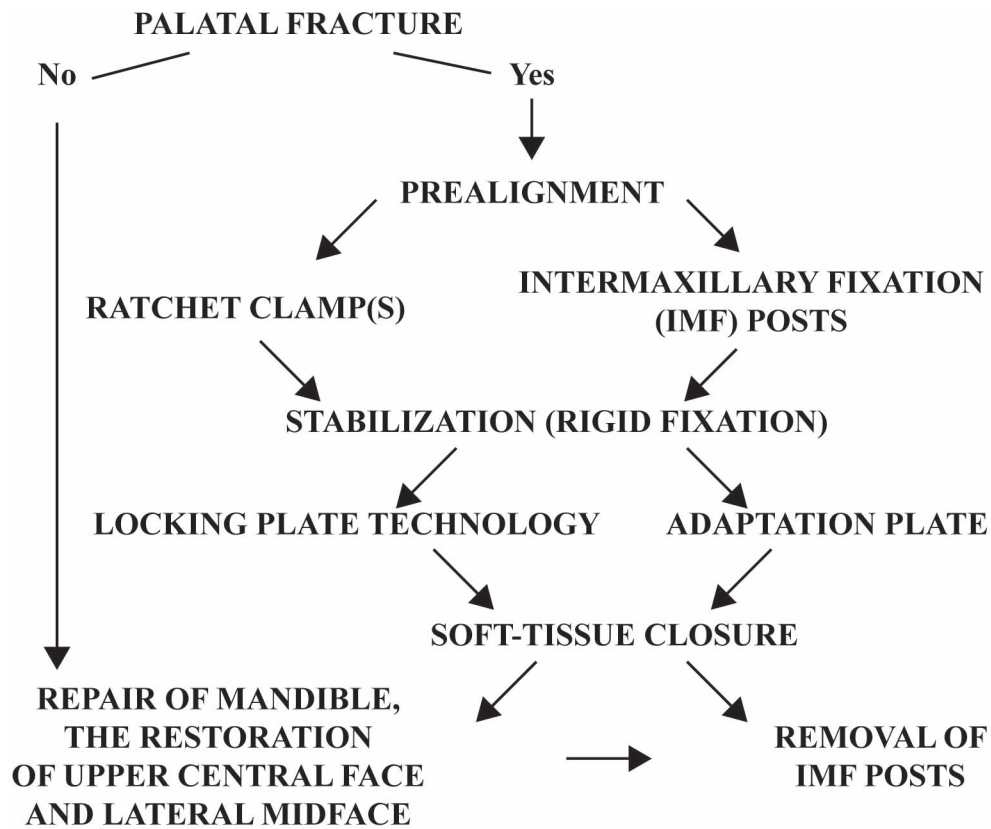


Fig. 4.31

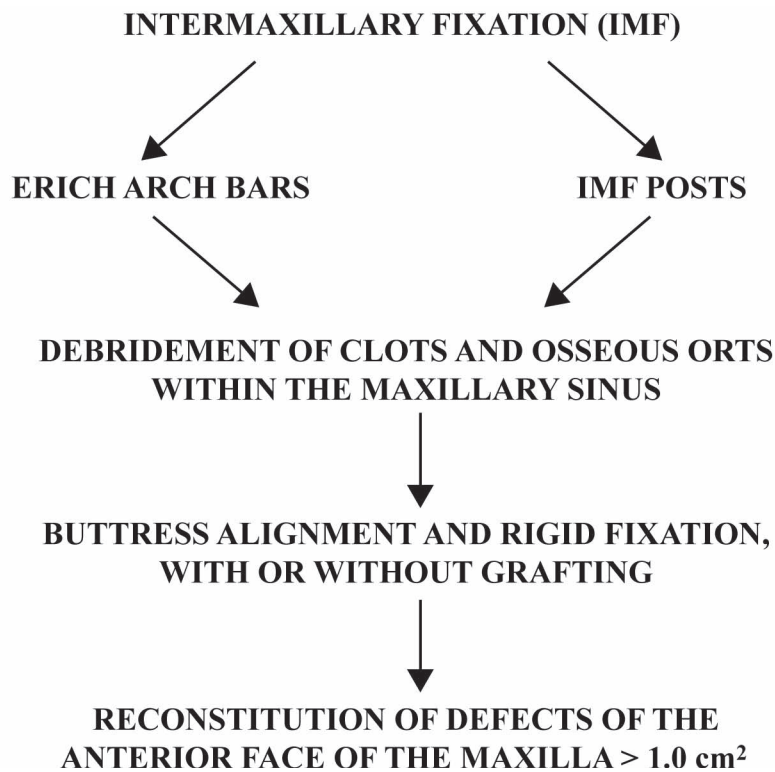


Fig. 4.32

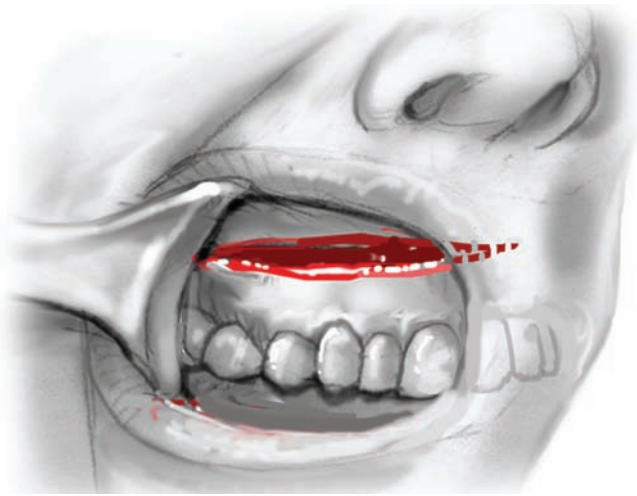


Fig. 4.33

some six points of compression along the dental arch prior to stabilization with locking plates and screws.

A segmental arch bar or orthodontic appliance may be added to curb a “wayward alveolus.”² The orthodontic bands in these selected cases are secured with cement, which is applied to the surface of the teeth; this construct is more comfortable and favors greater oral hygiene than an arch bar.

Rigid Stabilization of the Palatal Shelves

A 2.0-mm locking plate of 1.3-mm thickness is contoured to match the hard palate (Fig. 4.35A). More than one locking plate is chosen in the presence of oblique or comminuted fractures because of their inherent instability. Lacerations of the mucoperiosteum are not utilized as portals, and incisions in, and elevation of, the mucoperiosteum are avoided (Fig. 4.35A).

Locking screws have two threads: one to secure (“lock”) the plate and the other to engage the palatal bone.^{34–36} The locking plate does not intimately contact the mucoperiosteum, and the dual threads tend to proscribe loosening of the screws (Fig. 4.35B).

Screws 5 or 6 mm in length are chosen medially, particularly in the sagittal and parasagittal areas, to avoid penetrating the floor of the nose. Longer screws, perhaps 6, 7, or 8 mm in length, are elected in the para-alveolar (palatoalveolar) areas, as the bone tends to be much thicker (Fig. 4.35C).

The screws pass directly through the mucoperiosteum to engage the bone of the palatal shelves, giving the assembly the appearance of an *intraoral* external fixator.² The laceration within the soft tissue need not be closed, nor should mucoperiosteum be elevated.

As a final act of stabilization, a 1.5-mm (or 1.3-mm) adaptation plate, six holes in length, is applied across the fracture line as it leaves the palate to exit the anterior face of the maxilla (Fig. 4.36A).

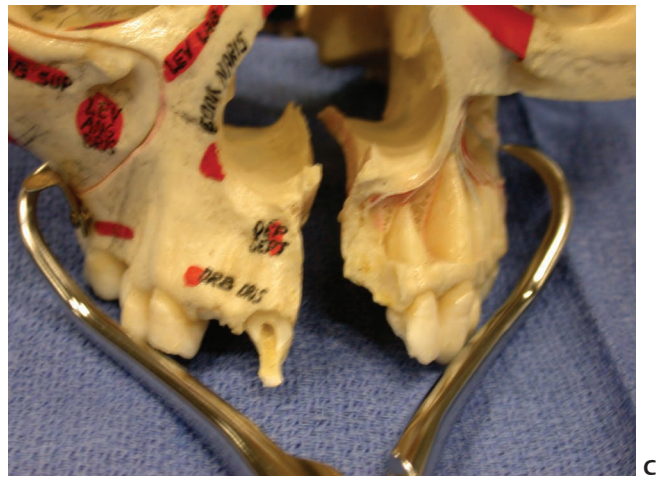
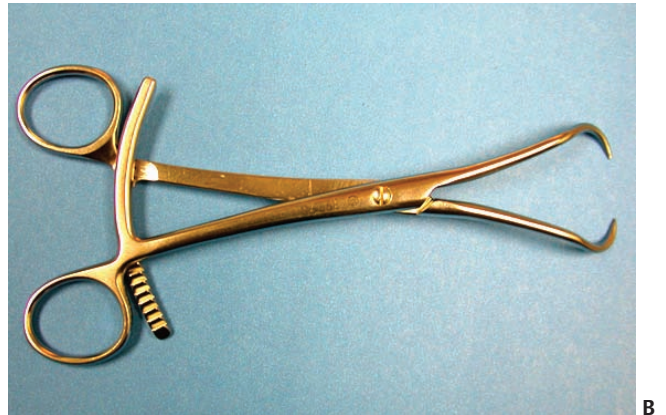
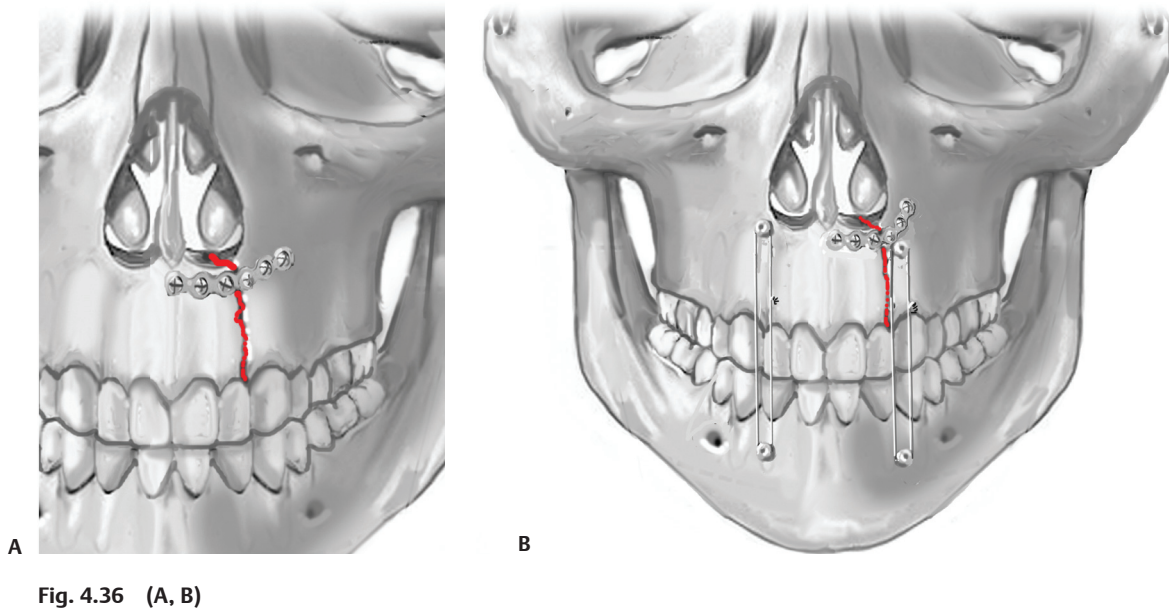
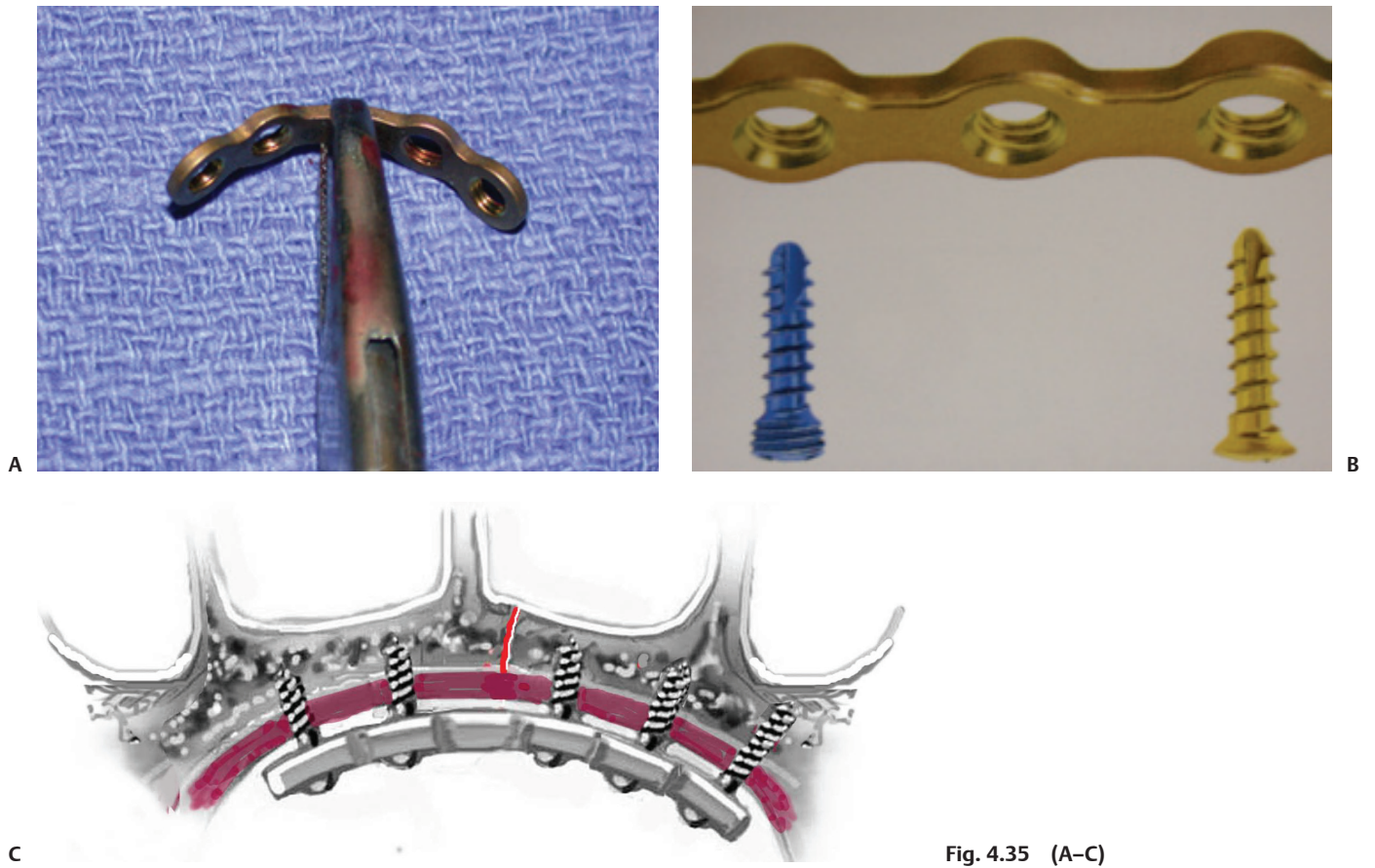


Fig. 4.34 (A–C)

The occlusal pattern is then checked as a final measure. To do so, opposing IMF posts are placed in the symphysis of the mandible, and the upper and lower dental arches are engaged by two loops of wire. Once the occlusion and the appropriate width and depth of the maxillary dental arch have been assured, the mandible and the lateral and medial craniomaxillofacial buttresses are then repaired (Fig. 4.36B).



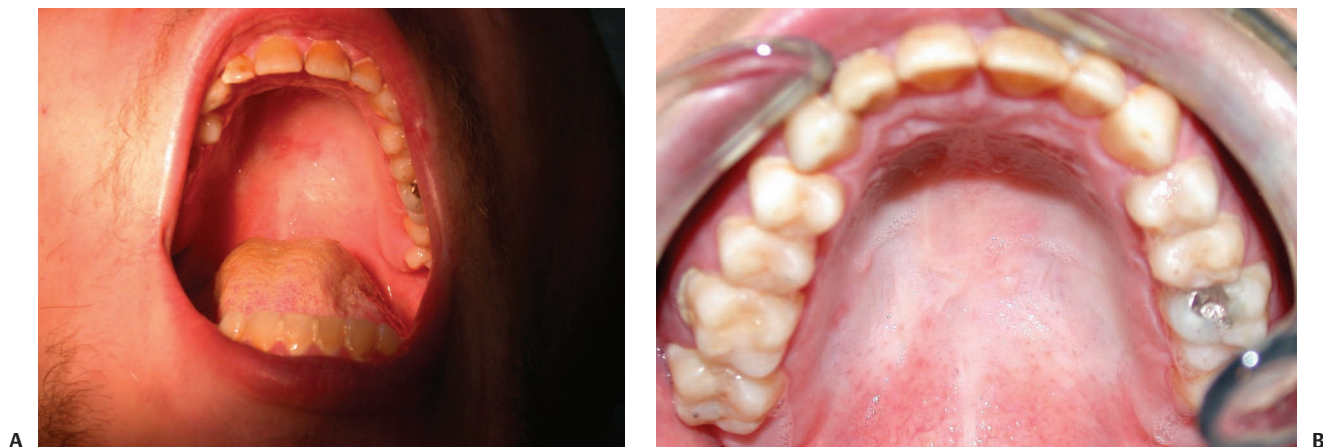


Fig. 4.37 (A, B)

IMF fixation is maintained if the instability of other fractures of the craniofacial skeleton requires but is otherwise discontinued. Motion and soft diet are permitted in the immediate postoperative period.

The locking plate(s)-and-screws assembly in the roof of the mouth is removed some 8 to 12 weeks after application under local or general anesthesia. The screw puncture wounds in the roof of the mouth heal quickly, following removal of the locking plate assembly, aided by the use of warm saline rinses (Fig. 4.37A,B).

Lower Midfacial Buttress Repair

Le Fort fractures present a spectrum of injury, such that some buttresses may be minimally affected, whereas in other cases they are comminuted in a major way.^{37–43} The classic patterns of midfacial fractures occurring along the lines of weakness of the face, as originally described by Le Fort, are often *not encountered* today. The great majority, rather, consist of permutations and combinations, sometimes with extensive comminution of the entire maxilla⁴¹ (Fig. 4.38).

The *least* injured of the anterior buttresses is the *first* to be repaired because proper vertical height is more apparent (to the surgeon) when realigning the less injured buttress. A curved 1.5-mm plate is adapted to the medial buttress along the contour of the frontal process of the maxilla at the nasal margin. Both cortices of the bone are purchased with each screw, except in the area of the alveolus, where monocortical screws are chosen, to avoid potential damage to tooth roots.

The appliance used to reconstitute the lateral midfacial buttress is often more substantial (compared with that applied to the medial buttress), and an L-shaped 2.0-mm plate (the frequent choice) provides the needed additional

rigidity and length. Contouring with pliers is usually required (see Chapter 7).

The anterior face of the maxilla is reconstructed as a final act of repair (sometimes with mesh). Bone grafts may be required to reconstitute the buttress or the anterior wall of the maxillary sinus when the defect is substantial (roughly 1.0 cm² or more).^{42,44} Split cranial bone is preferred as a graft and is harvested from the temporoparietal skull above the temporal line. A plate is first applied to the graft, and they are then inserted as an assembly⁴⁵ (see Chapter 3) (Fig. 4.39).

Approach to Collateral Damage

Crossbite

Postoperative malocclusion common to palatal fractures managed with intraoral splints or transpalatal wires is

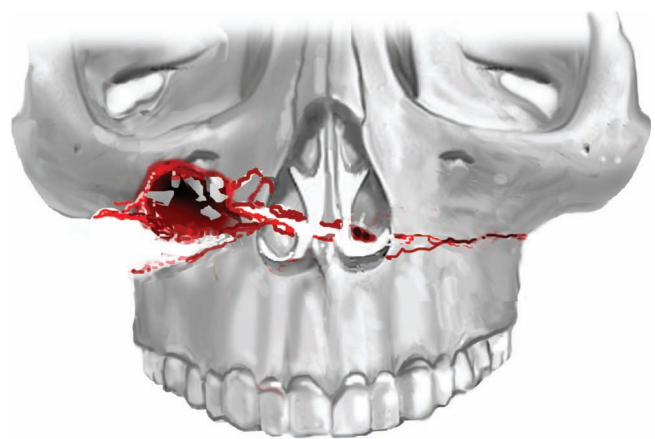


Fig. 4.38



Fig. 4.39

relatively less common when locking plate fixation is used.² A mild residual crossbite, when it occurs, is often readily corrected by orthodontic appliances.

Posterior or Posterolateral Open Bite

The posterior midfacial buttresses are often driven upward in a telescopic fashion toward the cranial base at the time of impact, and when they remain impacted or are incompletely mobilized with disimpaction forceps, a *posterior or posterolateral open bite* may follow. An open bite in the area of the posterior molars is then noted.

Anterior Open Bite

Erroneous disimpaction with forceps or fibrous union may paradoxically create an *anterior open bite*. This scenario, well described by Manson,^{46,47} is triggered by the laxity of the temporomandibular ligaments and by secondary, forward displacement of the mandible, relative to the maxilla. The ensuing Angle Class II malocclusion may occur after Le Fort I fracture but is more associated, in our experience, with a Le Fort II fracture.

Dental Loss

Late tooth loss may follow alveolar and/or lower midfacial fracture, and patients are best routinely forewarned of the possibility.

Ill-fitting Dentures

Patients with dentures should be monitored closely because dentures that fit poorly may provoke pressure attenuation or necrosis of the gingiva, leading to exposure

of the lower portion of the midfacial appliance. The mucosa and bone at the Le Fort I level are thin and delicate, and an isolated screw may loosen in areas of occult microfracture.

Septal Deviation

The lower central face, particularly the nasal-nasoseptal compartment of the nose (see Chapter 7), is vulnerable to concomitant injury, when palatal injuries occur. Septal hematoma and septal deviation (often a zig-zag deformity) are common and thus should be suspected.¹⁵ Flagrant deformities are best corrected acutely in our experience; moderate deviations can be postponed, however, to better assess their influence on nasal and sinus ventilation.⁴⁸

Maxillary Sinusitis

The maxillary sinus outflow tract and antechamber are above the level of most Le Fort I fractures and are spared injury, such that most patients with localized injuries avoid mucus outflow obstruction and chronic maxillary sinusitis after trauma. Patients that resume cigarette consumption are an exception, and they have a greater proclivity to sinus pathology over time, because of trauma- and smoke-induced hyperplastic change in the sinus mucosa.

Exemplary Repair

Case 1. Palatal and Mandibular Fracture

This patient suffered stacked lacerations of the *lower* lip at the midline and a parasagittal fracture of the palate with injury to several teeth, splaying of the palatal shelves, and a crossbite after a cycling accident (**Fig. 4.40A**).

Splaying of the palatal shelves was apparent on clinical exam and radiographic studies. The through-and-through lacerations of the *lower* lip were repaired, and a locking plate was contoured to match the prealigned roof of the mouth.

The locking plate assembly is shown, positioned in the vault, securing the palatal shelves, to again tolerate load share.

Training elastics and physiotherapy were used in the management of collateral damage: a concomitant fracture of the neck of the ipsilateral mandible (**Fig. 4.40B**). Pretraumatic occlusion was reestablished. Note the appropriate lower- and midfacial width, depth, and height after repair of the palate using locking plate technology (**Fig. 4.40C**).

Scar formation in the roof of the mouth is minimized by using the locking plate assembly. The punctured mucoperiosteum heals rapidly despite its penetration by four to five locking screws (**Fig. 4.40D**).



Fig. 4.40 (A-E)

The mandible and the restored palatal platform are keys to restoration of the dimensions of the lower third of the face. This patient is depicted several weeks following the injury. The retained unresorbable glabellar suture was removed (Fig. 4.40E).

Case 2. Lower Midfacial (Maxillary) Fractures

Le Fort I fractures of the lower midface aligned nicely after the use of precontoured Pollock-Dingman reduction forceps and were stabilized with plates and screws (Fig. 4.41A-C). Facial proportions and normocclusion

were restored (Fig. 4.41D-F). Five-year follow-up is depicted (Fig. 4.41G).

Case 3. Lower Midfacial (Maxillary) Fractures

This edentulous patient experienced bilateral Le Fort I fractures after a fall. The maxilla was disimpacted with precontoured (Pollock-Dingman) forceps and stabilized with plates and screws (Fig. 4.42A-C). Right infraorbital neuropathy characterized by dull pain and dysesthesias resolved in some 14 months (Fig. 4.42D,E). Facial proportions have been restored. New dentures were recommended (Fig. 4.42F).



Fig. 4.41 (A-G)



Fig. 4.42 (A-F)

Case 4. Lower Midfacial (Maxillary) and Zygomatic Fractures

A right zygomaticomaxillary fracture was repaired through gingivobuccal and lateral canthofornix incisions. Three-

point fixation was achieved (Fig. 4.43A-D). A 24-gauge prealignment wire is pictured. Excellent malar projection was restored. Several subtle asymmetries (nose and lip) were preexistent and had been noted in photographs taken prior to the injury (Fig. 4.43E,F).



Fig. 4.43 (A-C) (Continued)

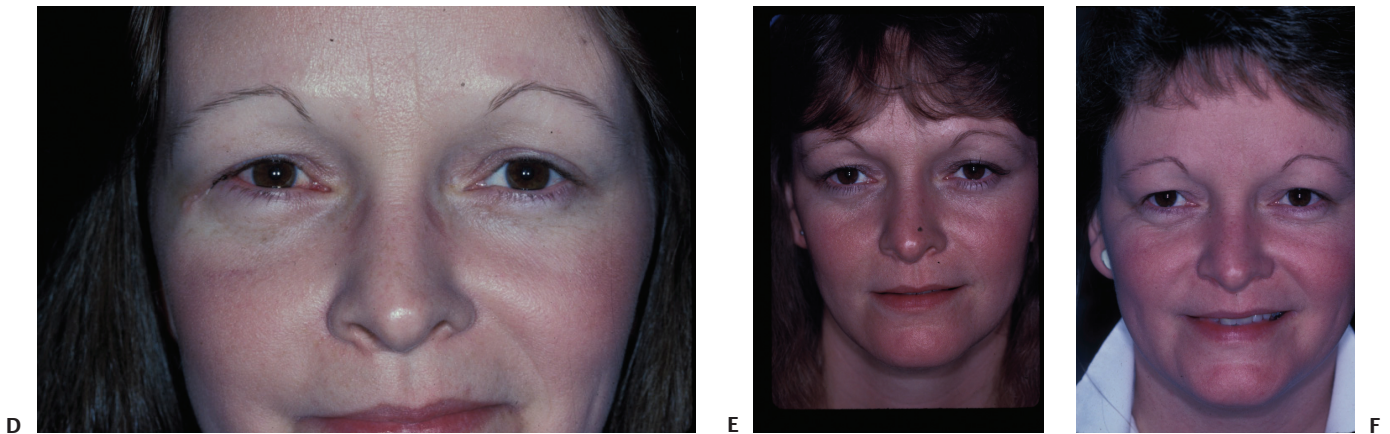


Fig. 4.43 (Continued) (D–F)

■ Key Points

The hard palate is the platform from which the seven mid-facial buttresses arise to engage the cranial base. Further, repair of the palate (if injured and unstable) has the greatest chance to bias the outcome of craniofacial repair in a “negative” or a “positive” way. The hard palate is thus the first to be repaired in pancraniomaxillofacial injury, then the mandible, thus restoring the maxillomandibular block. Further, fractures of the buttresses just above the alveolus do not today follow the original Le Fort patterns, but rather are permutations due to comminution and collateral damage. Reduction of the buttresses and proper placement of plates and screws is key to restoration of facial architecture, pretraumatic occlusion, and the sinus as a mucus-producing reservoir.

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5

The Mandible

With contributions by Warren Schubert

■ Part 1. Surgical Anatomy and General Considerations

The Mandible as a Tubular Bone

The mandible is basically a tubular long bone, the tooth-bearing portion of which is bent into a paraboloid (horseshoe-like) configuration.¹ The tooth-bearing portion is commonly referred to as the “anterior segment,” and that more distal as the “posterior segment” (Fig. 5.1A,B).

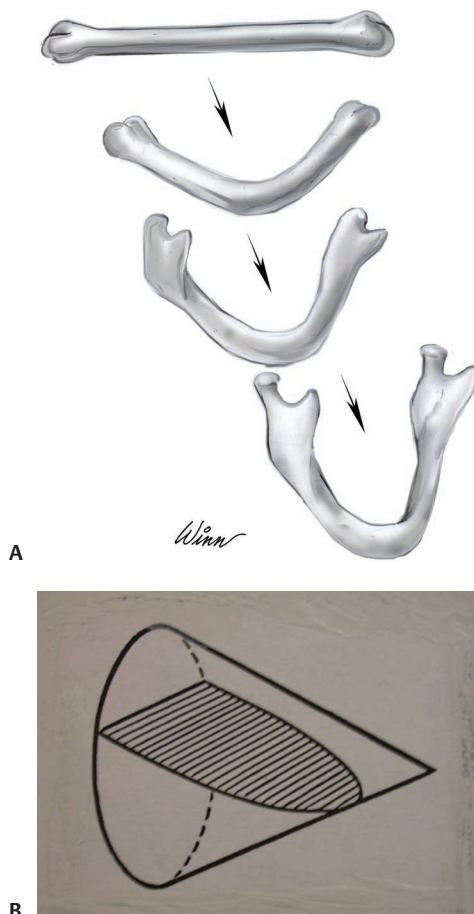


Fig. 5.1 (A, B)

Beyond the dentition of the anterior segment, the tubular bone angulates, then ascends and flares outwardly to provide bilateral (condylar) contact with the glenoid fossa of each temporal bone at the lateral cranial base (Fig. 5.2A,B).

The alveolar process of the mandible is more robust than the alveolar process of the maxilla.² The mandible lacks a horizontal platform (such as the palate), but strength is conferred instead by its substantial inner and outer cortex and inferior margin.

The comparative smoothness of the outer surface (cortex) of the mandible varies by region, depending on physiologic and mechanical demand. The angle of the mandible, for example, is grooved (because of the attachment and function of the masseter and the medial pterygoid muscles), the coronoid process is roughened (by the action of the temporalis muscles), and the upper outer surface of the lower jaw is thickened (alveolar bone) to accommodate the developing teeth and their roots after eruption²⁻⁴ (Fig. 5.3).

Studies using a Zeiss Videoplan digital analyzer (Carl Zeiss, Oberkochen, Germany) to assess cross-sectional area support the concept of the mandible as a modified tubular bone, albeit with distinct regional features and distinct load-sharing characteristics. These studies suggest more total similarity than difference in the bone of the tooth-bearing mandible. From angle to angle, for example, in the “anterior segment,” there is little difference in *total* bone surface area, cortical bone surface area, or spongiosa.⁵ Further, the cross-sectional area of mandibular bone around the third molar is not statistically different than that in, say, the body, parasymphysis, or symphysis. Similarly, the cross-sectional area on either side of the canine is no different than that of the symphysis or the body, despite outward regional appearances (Fig. 5.4A,B).

The mandible continues upwardly beyond the dentition as the “posterior segment,” where the total cross-sectional measures progressively fall from the distal angle and ramus en route to the coronoid process and condyle.

The total cross-sectional area of each mandibular section is depicted and expressed as a relative percentage of the total cross-sectional area *at the symphysis*⁶ (Fig. 5.5A-C).



A



B

Fig. 5.2 (A, B)

Contrasting the Upper and Lower Margins

The cortical bone is thick along the *lower* border of the mandible, in the areas of the symphysis, parasymphysis, and anterior body (Fig. 5.6A). In the area of the posterior body, the cortical bone begins to thicken in the upper border to house the molar teeth (Fig. 5.6B). At the distal angle, the cortical thickening reverses, such that the cortical bone at the lower border is relatively thin, just distal to the last molar. There,



Fig. 5.3

the maximum thickness is at the *upper*, rather than the lower, border (Fig. 5.6C).^{2,5} At the junction of the angle and ramus and in the subcondylar area, the relative dominance of cortex at the anterior border remains (Fig. 5.6D,E).

Cancellous Internal Structure

The space between the outer and inner cortices contains cancellous bone (spongiosa) divided by trabeculae. The trabeculae of this central, cancellated tissue vary in thickness and compactness, and large, bone-free spaces frequent the anterior segment³⁻⁷ (Fig. 5.7).

The stress loads borne by mastication reach the periodontal ligaments and in turn the surrounding, compact, alveolar bone (*lamina dura*) lining each tooth socket. The alveolar bone per se tends to micro-oscillate if the tooth is under sufficient stress loads, and this micromovement is resisted in turn by the cancellated tissue.

Some of the spongy trabeculae surrounding the apical aspect of the tooth sockets unite as the *dental trajectory*, passing backward beneath the sockets and then extending diagonally upwards and backward through the ramus, to end in the *condyles*. This internal trajectory corresponds to a rounded crest on the medial surface of the ramus, the so-called *ridge of the mandibular neck*⁴ (Fig. 5.8A,B).

The trajectories along the lower border of the mandible and the dental apices are joined by the *coronoid trajectory* as it descends from the tip of the coronoid processes. Created by the forces afforded by the muscles of mastication, the coronoid trajectory tends to fan out over the medial and lateral surfaces of the angle and posterior body of the mandible.⁷

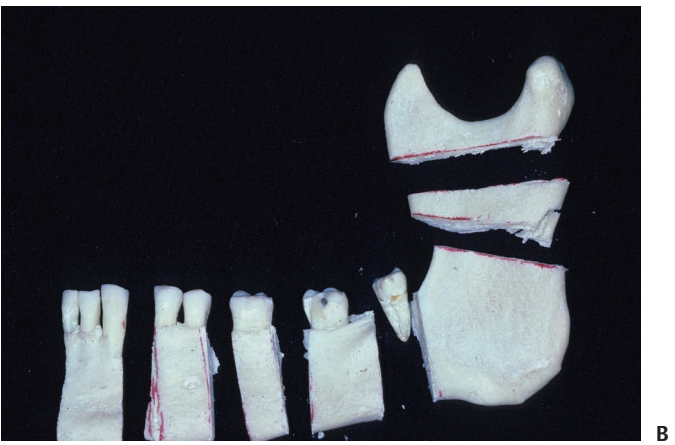


Fig. 5.4 (A, B)

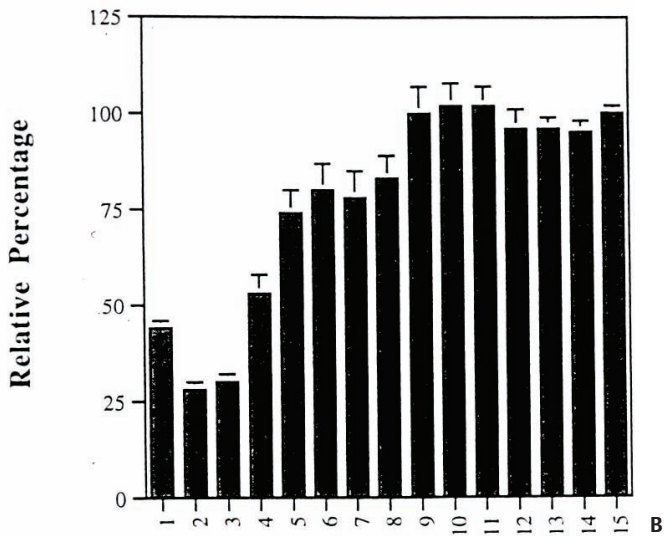
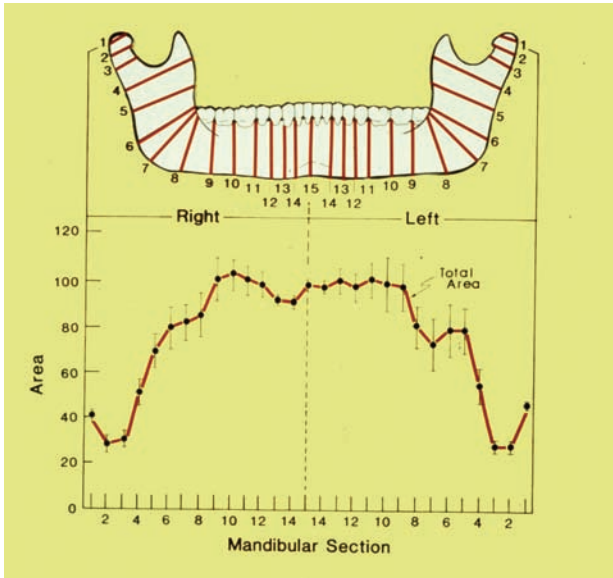


Fig. 5.5 (A-C)

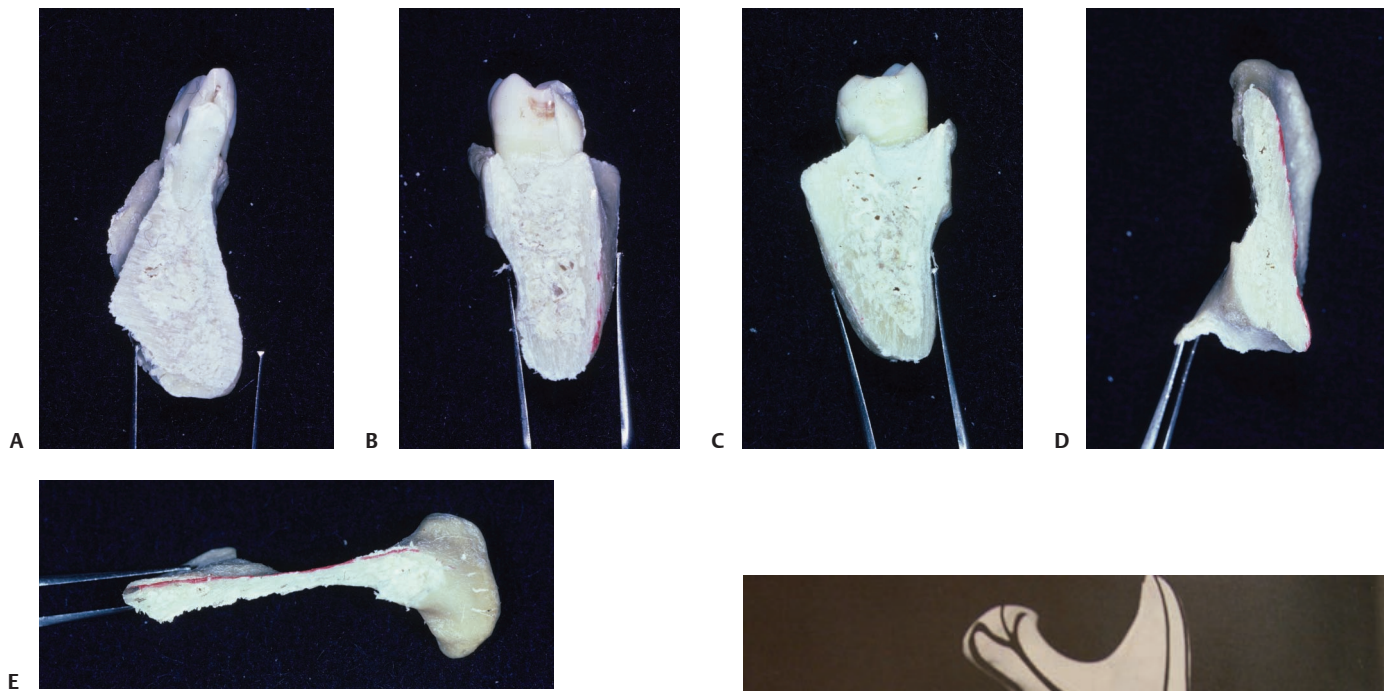


Fig. 5.6 (A-E)



Fig. 5.7

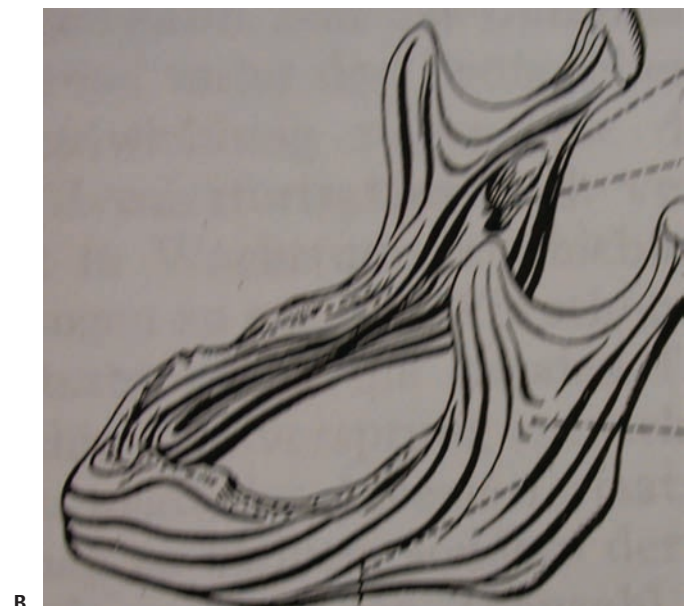


Fig. 5.8 (A, B)

Blood Supply of the Mandible

The mandible, mandibular vestibule, and anterior floor of mouth enjoy a rich blood supply by way of terminal branches of the external carotid artery. In the case of the mandible, distribution is by endosteal and by inner and outer periosteal systems.

The internal maxillary artery, one such branch of the external carotid, is first embedded in the deep lobe of the parotid gland, behind the neck of the mandible. Several branches are given off at this location, including the *inferior alveolar artery*, the endosteal supply to the mandible. The inferior alveolar artery plunges downward, passing through the parotid gland to reach the *mandibular foramen* on the lower, medial surface of the ramus of the mandible.^{8–19}

Just before entering the mandibular foramen, the inferior alveolar artery gives off a *lingual branch* and a *mylohyoid branch*. The lingual branch descends with the lingual nerve to supply the mucous membrane of the floor of the mouth, and the mylohyoid vessel runs in the mylohyoid groove and then ramifies on the undersurface of the *mylohyoides*, thus supplying the periosteum of the lower inner cortex.¹¹ These branches of the inferior alveolar artery are supplemented in the floor of the mouth by the *deep lingual artery*, a direct branch of the external carotid artery. Note that the blood supply to the inner cortex is tiered above and below the mylohyoid muscle. This three-tiered distribution of vessels is readily seen in an oblique lingual view of the right mandible and in an exemplary cross-section in the area of the left parasymphysis.

The *inferior alveolar artery* passes along the mandibular canal, then bifurcates opposite the *first premolar* tooth into mental and incisor branches. During their course forward, random “twigs” are issued to the cancellous (trabecular) bone, and more orderly branches are provided to the roots of the teeth. These dedicated vessels enter diminutive apertures at the extremities of the roots to supply the pulp of the teeth.^{11,12,18,19} The *incisor branch* of the inferior alveolar artery continues forward within the substance of the mandible to reach the midline, where it anastomoses with the artery of the opposite side (**Fig. 5.9**).

The mental branch emerges with the mental nerve from the mental foramen to anastomose with the *submental, inferior labial, and facial arteries*.^{20–23} These three vessels supply the outer cortex in a more random pattern than the tiered pattern of blood supply enjoyed by the inner cortex.

The rich arborization of vessels in the mandible was noted by Cryer at the turn of the 19th century³ and was dramatized by the subsequent studies of Knapp and Dempster and colleagues.^{20–23} They revealed the extensive endosteal vascularity by injecting India ink after the extraction of organic material with ethylenediamine, similar to the injection of contrast as a prelude to modern radiographic study (**Fig. 5.10**).

The Mandibular Nerve

The mandibular nerve enters the *mandibular foramen* and curves outwardly to become most buccal, opposite the *third molar*. From there, the nerve curves lingually before exiting the mental foramen.¹¹ The egress is characterized by a spray of mental, sensory branches to the lower lip and chin, most evident when an incision is made in the *mandibular sulcus* to expose a fracture of the symphysis or parasymphysis (**Fig. 5.11A,B**).

■ Part 2. Operative Technique and Exemplary Repair

Occlusion is a dynamic concept, and, according to Sicher, occlusal positions are “all those in which contact between some or all upper and lower teeth occurs.”⁷ Median occlusion represents the interdigitation of mandibular teeth against maxillary teeth, and, as noted by Dingman and Natvig, maintenance of median occlusion is important to ongoing healing osteosynthesis of the fracture site.²⁴ Current rigid fixation devices have freed patients from the untoward sequelae and inconvenience of prolonged, intermaxillary fixation (IMF) after surgery.

The maxillary and mandibular *first molars* are guides for estimating normal occlusal position²⁵: the mesiobuccal cusps of the maxillary first molars should align with the mesiobuccal grooves of the mandibular first molars. A slight overbite and an overjet of the anterior teeth are allowed. The engagement assumes what is colloquially called the [Davenport-Angle] “occlusal plane” (see annotated references 5 and 18 in the Additional Bibliography of Chapter 2) (**Fig. 5.12**).

Intermaxillary Fixation

Establishing maxillomandibular (so-called intermaxillary) fixation is a significant measure in the repair of all lower facial fractures, whether with Erich arch bars, Ernst ligatures, or intermaxillary posts and wire loops (**Fig. 5.13A–C**).

“Seating” of the condyles in their appropriate position (craniomandibular articulation) is key to reestablishment of the dimensions of the lower third of the face.

Potential Bias of Intermaxillary Fixation

Appliances used to achieve IMF are easily applied and often utilized as an initial step in operative repair. In some instances, however, IMF appliances create bias that must be overcome (by rigid stabilization), because the IMF appliances complement forces at the fracture site, *tending to rotate the fragments in a lingual direction*.

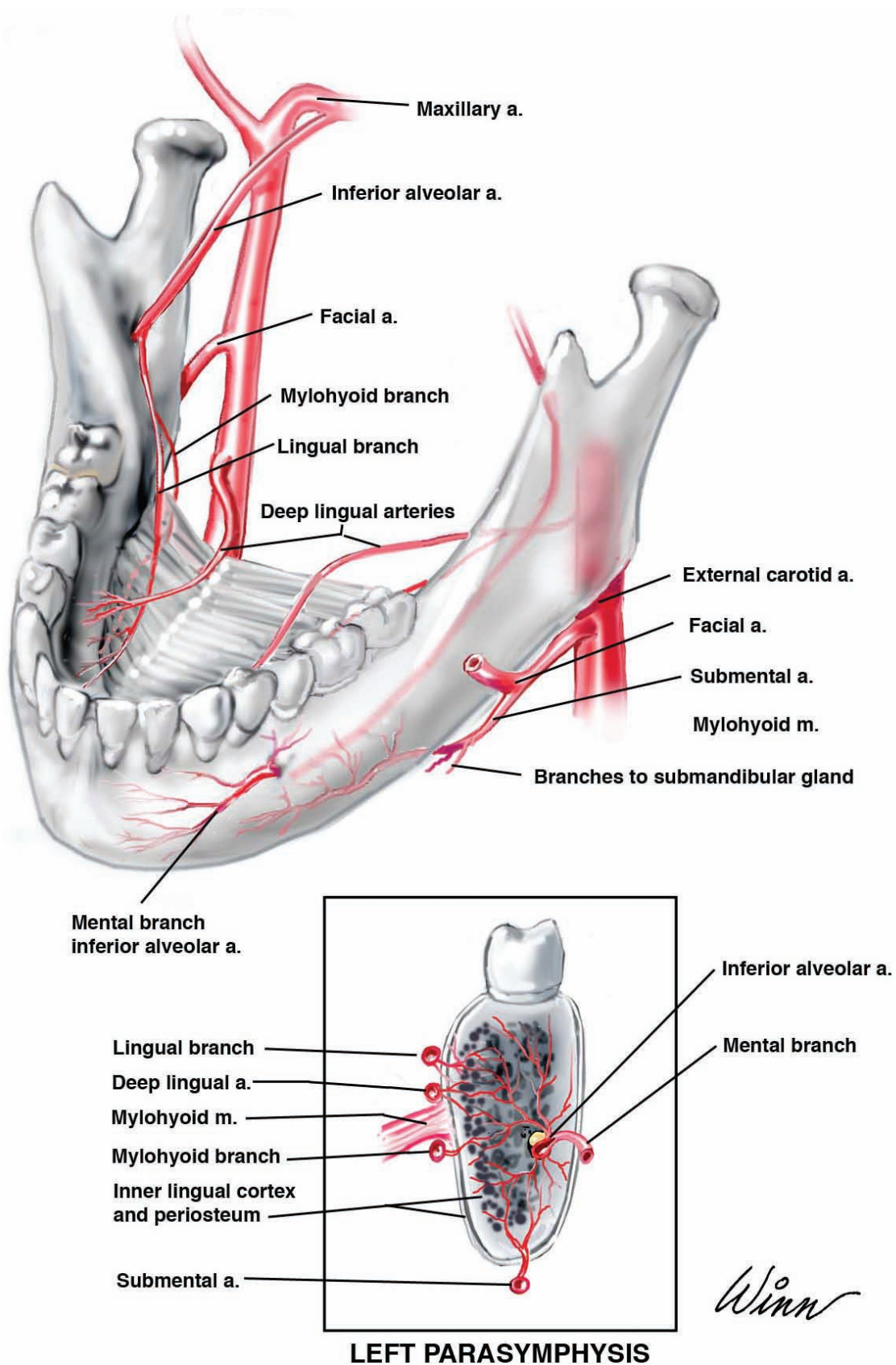


Fig. 5.9

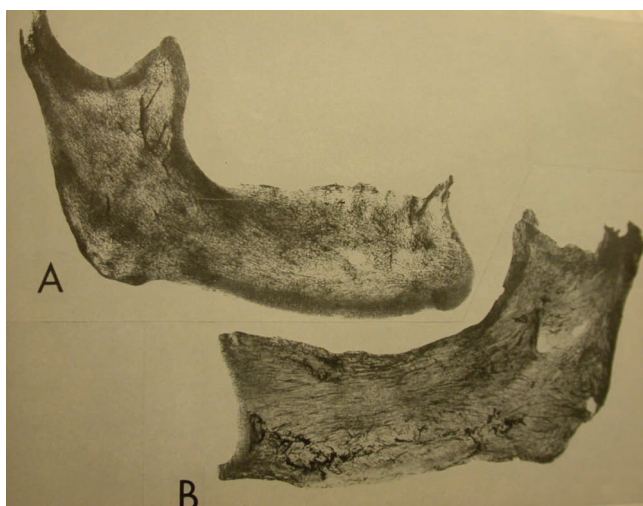


Fig. 5.10

Lingual (dental) version is seen most with fractures of the body of the mandible that are *mesial* to the molar teeth. For example, fractures occurring within the body are subject to the downward and inward pull of the mylohyoid muscle, such that the inferior margins of the fragments tend to splay outwardly. Elastics applied to the labial surface of the upper and lower teeth complement the mylohyoid “pull” and add a second force (in the same direction), favoring fragment version instead of reduction (Fig. 5.14).

Because of this disadvantage, interdental wires and intermaxillary elastics have limited postoperative use, except with fractures of the body distal to the molar teeth, condylar fractures, and so-called simple maxillary fractures.²⁶

Pretraumatic Malocclusion

Because pretraumatic malocclusion is common, it is important to assess dentition and occlusive patterns *preoperatively*. Abnormal wear facets, crowding, and other features are carefully documented before surgery is initiated, as they may significantly bias repair and could lead to false claims of induced malocclusion after surgery. Normal (“neutral”) occlusion and two classes of malocclusion (distocclusion and mesiocclusion) have been thoroughly described as Classes, I, II, and III, respectively.^{7,24}

The relation of the mesiobuccal cusp of the maxillary first molar to the mandibular teeth is the key upon which Angle’s classification of occlusion is based (Fig. 5.15A–C).

Muscle Attachments and Their Influence

A detailed discussion of the mandible and its attachments can be found in standard books or atlases of anatomy, but the surgeon should be aware that *basic movements* of the mandible depend upon *two groups of muscles*.

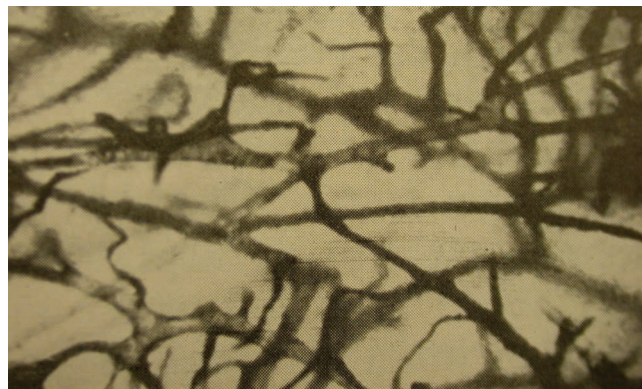
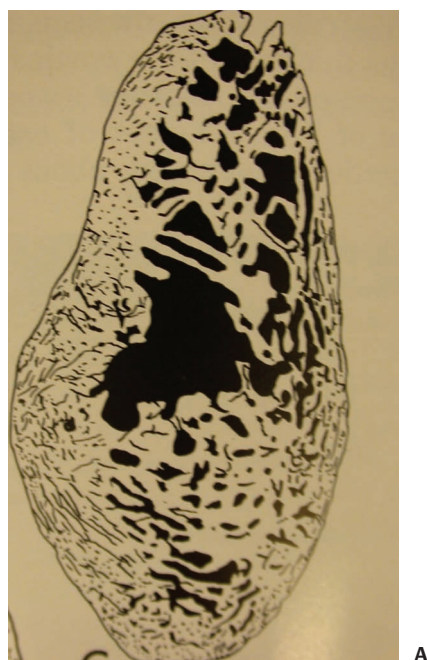


Fig. 5.11 (A, B)

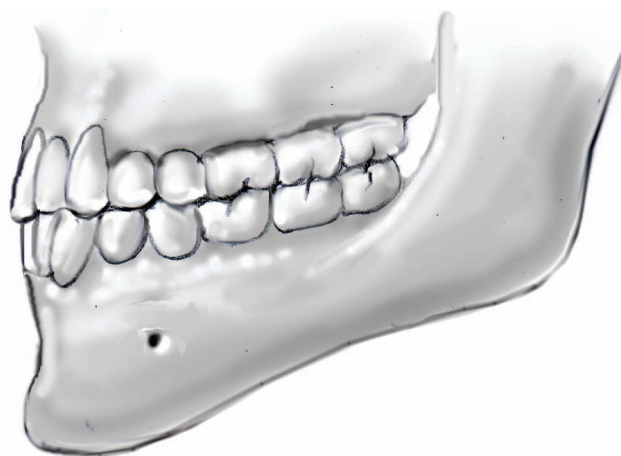


Fig. 5.12

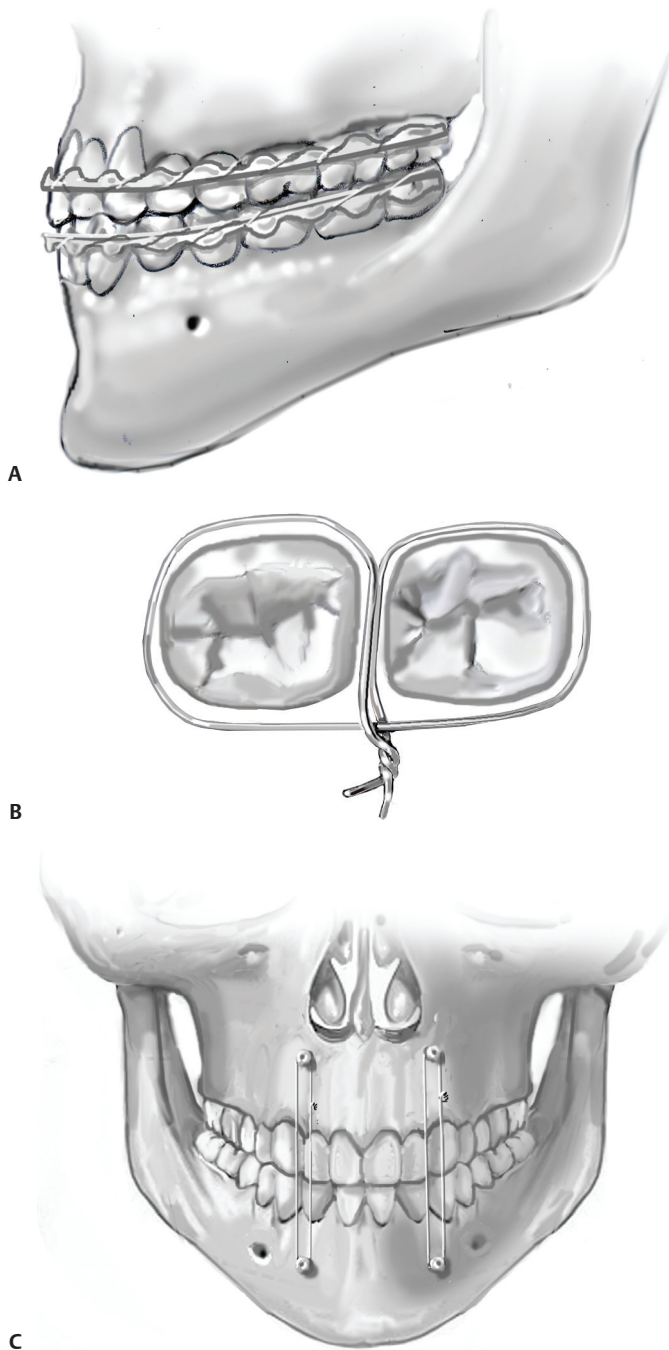


Fig. 5.13 (A–C)

These muscle groups may influence the position of the fractured segments,^{7,24,27,28} such that the fracture is considered “functionally stable” (thus “favorable”) or “functionally unstable” (thus “unfavorable”). The muscles of facial expression attached to the mandible have no significant effect on fractured segments.

The geniohyoid and digastric muscles act in concert as a depressor-retractor group; they are the weaker of the two



Fig. 5.14

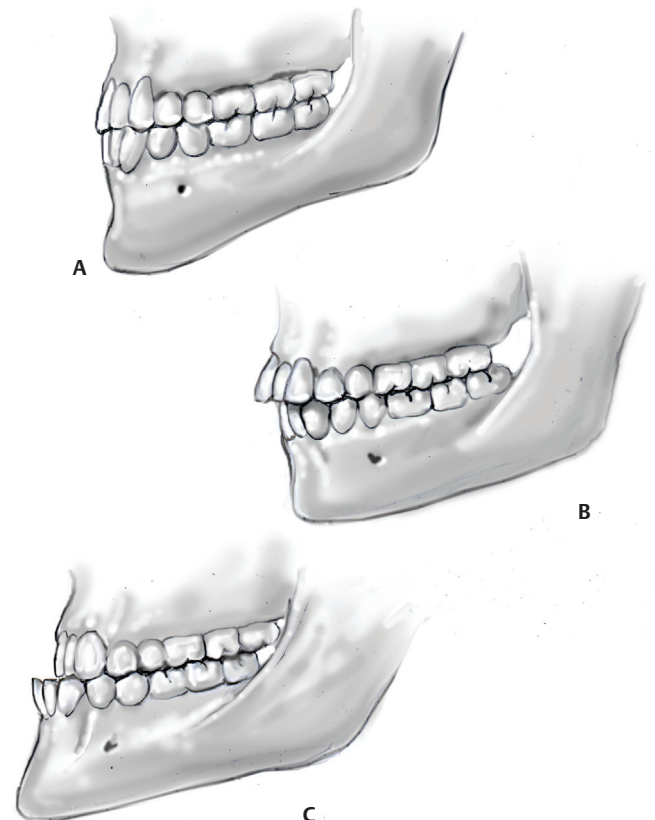


Fig. 5.15 (A–C)

systems. The masseter, temporalis, and medial pterygoid are comparatively powerful and serve to elevate the lower jaw, as the stronger system of muscles.

The lateral pterygoid is a major force in the protrusion of the mandible, and the mylohyoid has modest influence, because most of its fibers join in the midline at the mylohyoid raphe. The mylohyoid, nevertheless, may cause inward (lingual) rotation and splaying after fracture because of its high plane of attachment to the anterior segment.

The bias on fractures created by these muscle attachments has been thoroughly described by other texts.^{7,24} They, the presence of dentition, and the pathomechanics of impact profoundly affect the clinical presentation and radiographic findings of the injured patient (Fig. 5.16A–C).

Regions of Mandibular Fractures

Mandibular fractures may be characterized by the type of fracture: greenstick, simple, complex, or comminuted. However, a classification according to anatomical location is more germane to most clinical settings, as offered by Dingman and Natvig, with modification²⁴ (Fig. 5.17):

- *Region of the symphysis and parasymphysis.* This is the region bounded by vertical lines mesial to the first premolar.
- *Region of the body.* This region extends from the premolar line to a line that coincides with the anterior border of the masseter muscle.
- *Region of the angle.* The region of the angle is triangulated and bears the attachment of the masseter.

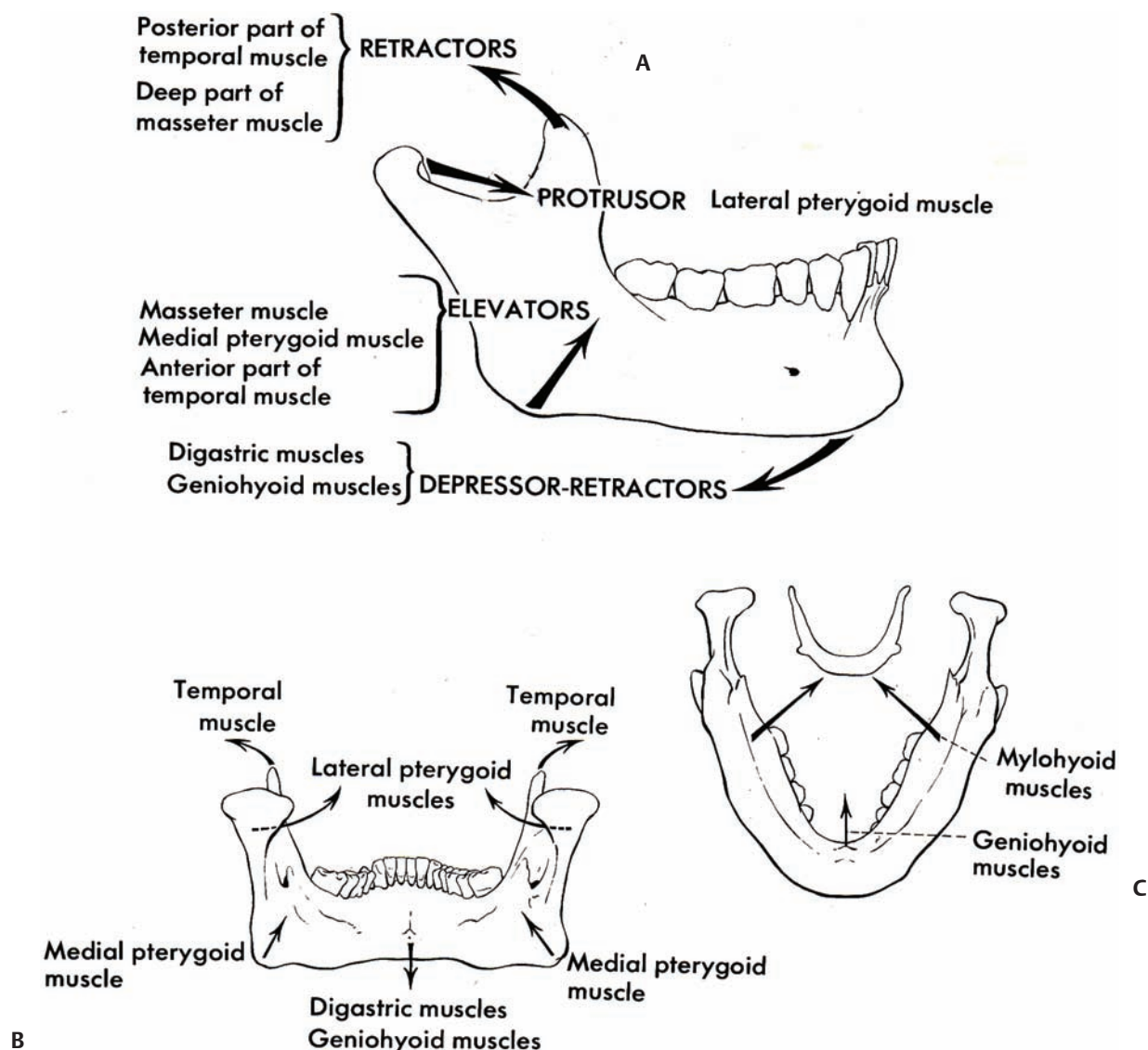


Fig. 5.16 (A–C)

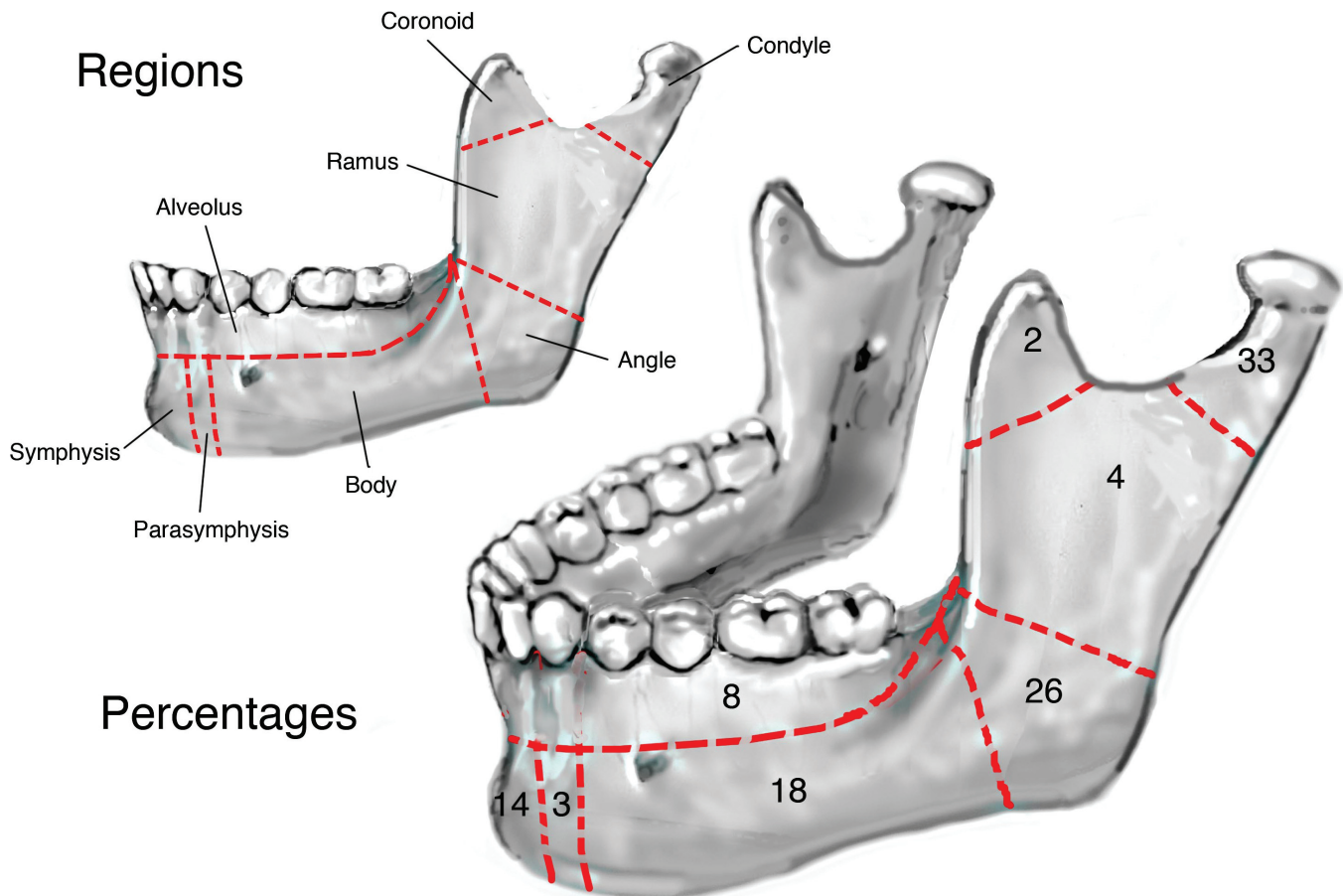


Fig. 5.17

- *Region of the ramus.* This region is bounded inferiorly by the region of the angle and superiorly by two equal lines dropped at 90 degrees from the sigmoid notch.
- *Region of the condylar process.* This region comprises the condylar process above the ramus. It includes the neck and the mandibular condyle.
- *Region of the coronoid process.* This region includes the coronoid process above the ramus.
- *Region of the alveolar process.* This region is restricted to the alveolus.

Proclivity to Fracture

The sites of predilection for fracture^{27,29–32} were identified in general by cinematography at many frames per second in the 1960s,^{33–38} relatively confirmed by cross-sectional studies in the 1980s and 1990s that depict the mandible as a tubular bone,⁴ and refined recently by finite analysis.^{39,40} The finite studies describe the mandibular trajectories as *load-bearing pathways*, as reviewed in Chapter 2.

The higher incidence of fractures of the mandible in the area of the symphysis-parasympysis and in the body cannot be explained by cross-sectional area. The proclivity to fracture in these regions of the anterior segment appears rather to depend on the presence of dental roots, the location of the mental foramen and mandibular canal, tooth abutments, and the sites of insertion of the muscles of mastication,⁴ to name a few.

The incidence of fractures of the angle and particularly the region of the posterior segment near the condyle(s) is, by comparison, in part explained by cross-sectional area. The fracture line often passes obliquely downward and backward, from the sigmoid notch to the posterior border of the upper ramus. The fracture is extracapsular in this region and is colloquially labeled a *subcondylar fracture*.⁴¹

Condylar fractures may reach more proximally, within the anatomical neck, or may reach the joint cavity, with comminution.

Dislocation of the condyles into the middle cranial fossa may occur. As noted by Fonseca,⁴² however, when the mentum is struck with the mouth open (as in surprise), the medial and lateral poles of the condyles are impacted against



Fig. 5.18

the more thickened (medial and lateral) margins of the glenoid fossa. The prepositioning prevents the condyles from penetrating the more vulnerable center of the roof of the glenoid fossa. The thin roof of the glenoid (mandibular fossa) just anterior to the petrous pyramid is made apparent when viewed from above under appropriate lighting (**Fig. 5.18**).

Fracture of the subcondylar region reduces the likelihood of penetration of the glenoid fossa and entry of an intact condyle into the cranial vault by decompressing the load force (**Fig. 5.19**).

With fractures of the glenoid fossa, the condyle(s) may on occasion be displaced *outside* the fossa. High-resolution computed tomography ferrets out this unusual variant.

Fractures of the ramus exhibit relatively little displacement, because, to a large extent, the fractured segments are splinted by the masseter and medial pterygoid muscles. Similarly, fracture of the coronoid is splinted by the tendinous insertion of the temporalis muscle.²

After the subcondylar region, the angle has a large incidence of fracture. The angle fracture line begins at the inner cortex, passes to the outer (buccal) cortex, and may extend to involve the posterior body or adjacent alveolus. The fault commonly traverses the *anterior* root socket of the third molar, then obliquely reaches the *distal* root socket of the third molar, to exit through the outer (buccal) cortex (**Fig. 5.20**).² The inward and backward obliquity of this angular fracture may bias segment manipulation and realignment at surgery. On occasion, the molar at the site

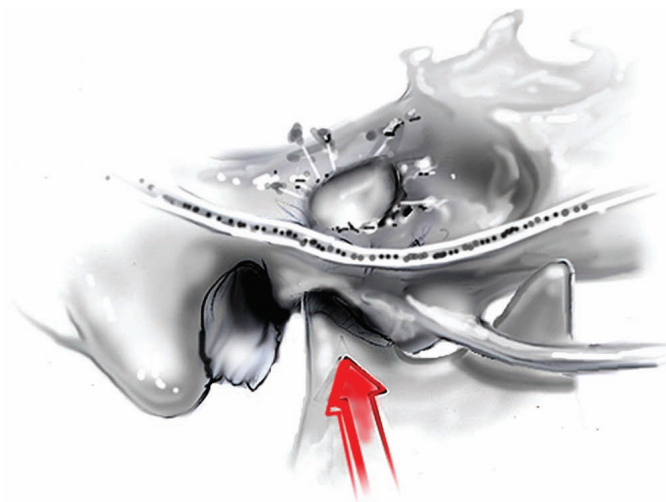


Fig. 5.19

of fracture must be extracted to complete reduction of the fragments, but more often than not, the molar is used to maintain the operative realignment.

Most fractures of the body are buttressed by the dentition, particularly when impact is delivered from a lateral



Fig. 5.20

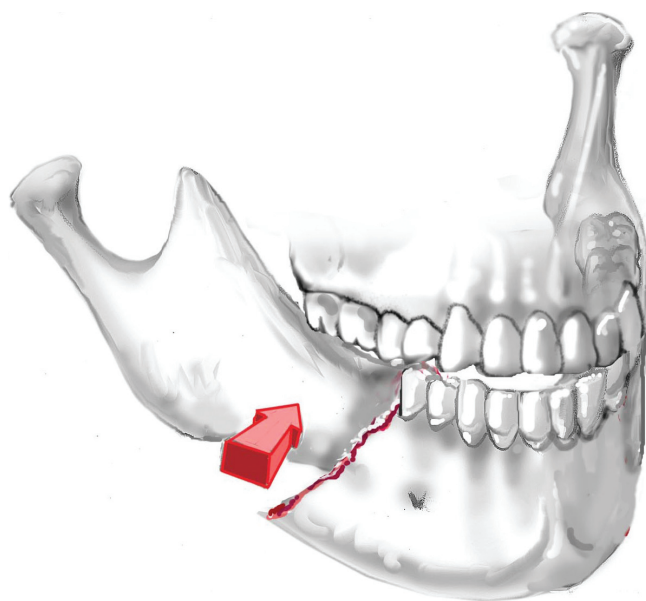


Fig. 5.21

source. The powerful muscles attached to the ramus tend to displace the proximal body fragment, particularly when edentulous, upward, and inward relative to the maxillary teeth (Fig. 5.21).

Fracture through the thick, inferior border of the symphysis is unusual but tends to be oblique when it occurs. The fragment from which the genial muscles arise tends to be displaced lingually, and both fragments consistently rotate medially, because of the medial pull of the mylohyoid muscles.² The medial rotation is apparent on clinical presentation because the incisors adjacent to the fracture line consistently overlap and the anterior segment tends to splay at the angles (Fig. 5.22).

The obliquity of the fracture makes realignment of the fragments difficult. Once reduced with forceps, however, the fracture can be stabilized with two or more lag screws, aided by inward pressure at each angle (by a surgical assistant). Alternately, the fracture can be stabilized with a strong, bicortical locking plate at the lower margin and a monocortical tension band more superiorly. When the fracture occurs near the deep root of the canine or involves the mesial roots of the first premolar, it is referred to as a *parasymphyseal* fracture.

Preoperative Assessment and Indications for Repair

Clinical Presentation

Low-velocity fractures cause less dislocation and simplify clinical examination. Soft-tissue swelling may be minimal, and airway and vascular compromise are less often witnessed.

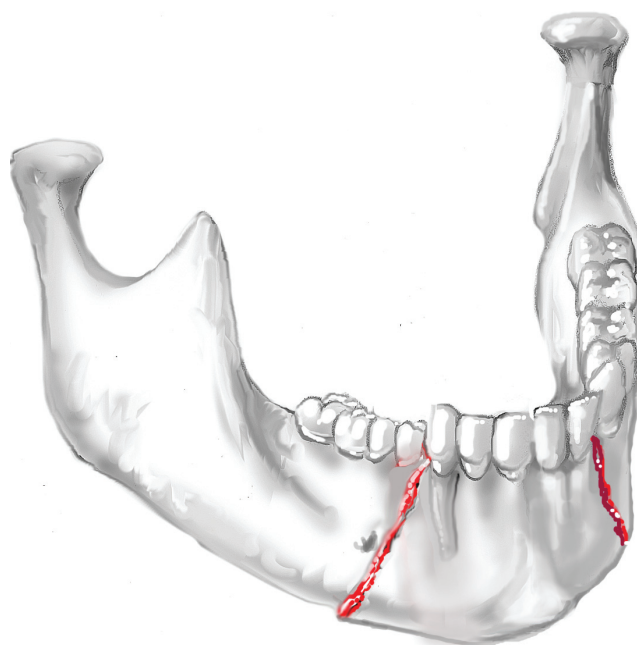


Fig. 5.22

With improved restraint systems, rapid retrieval, and triage of the severely injured, a greater number of patients survive high-velocity fractures. Airway compromise is often reversed, hemorrhage is frequently contained, and limited fluid resuscitation is commonly initiated (see Chapter 3) before arrival at tertiary centers.

Discomfort is often present with motion and palpation over the site of injury. The least movement of the jaw may trigger excruciating pain, and thus chewing, speaking, or swallowing are minimized. Clinical examination may be compromised. Swelling, ecchymosis, hematoma, or crepitus in the vicinity of fracture “flags” the site of injury.

Damage to teeth may occur in conjunction with the fractures of the anterior segment and are most common in the symphysis and parasymphysis, where the teeth are relatively exposed. The teeth of the body may be sheared off at the time of impact. Teeth in the line of fracture are often a benefit to prealignment and stability of the fragments, even after rigid appliances have been applied. Nevertheless, if a single tooth or a proximal fragment interferes with reduction, the tooth is removed.

Numbness in the distribution of the mental nerve to the chin and lower lip is usually transient but frequently reported. Approximately 15% of patients have persistent areas of hypesthesia or anesthesia 2 years following fracture in uncontrolled study.

Displacement of the mandibular fragments may be suggested by the presence of asymmetry and *deformity* of the lower face. Bilateral subcondylar fractures, with upward and backward telescoping of the rami, typically trigger an open bite and the appearance of elongation of the face.^{7,24}



Fig. 5.23

Displacement sufficient to cause malocclusion increases the odds of finding an open fracture (Fig. 5.23).

With displacement of the condylar neck, the mandible tends to shift toward the fractured side when any attempt is made to open the mouth. And, on protrusive motion, the jaw also shifts to the side of injury because of the relative inability of the lateral pterygoid muscle to function on the side of injury.²⁴

Multiple fractures of the mandible are common. More than one fracture of the mandible is present in one of five or six cases. The incidence of distortion and malocclusion is greater in these more complex circumstances.

The Mandible as an “Osseous Ring”

Some clinicians describe the architecture of the mandible as though it was a “ring” and draw an analogy to the pelvis, where more than one fracture is common. The analogy to the “pelvic ring” would require, however, that the temporosphenoid aggregate (cranial base) and each glenoid fossa be an integral part of the mandibular architecture and, clearly, this is not the case.

Degloving Injuries of Adolescence

High-speed cinematography at 2000 to 3000 frames per second demonstrates that after impact at the midline (symphysis), the mandible is inwardly (posteriorly) displaced. The mandible may “snap-back” after impact to a relatively normal position; the injury may then be suggested only

by detachment of the periosteum (and adjacent soft tissue) from the *inner* cortex and a void deep in the floor of the mouth. Bilateral symphyseal (or parasymphyseal) fractures and the more pliable bone of adolescence favor a higher incidence of oral degloving injuries in childhood. Denudation in these cases is presumably also favored by the immature attachment of the periosteum and the mylohyoid, genioglossus, geniohyoid, and digastric musculature to the inner cortex of the anterior segment of the mandible²⁸ (Fig. 5.24).

Radiographic Assessment

Fractures of the anterior segment of the mandible can generally be detected by routine views of the mandible. These so-called plain films do not, however, adequately reveal fractures of the posterior segment, notably those involving the upper ramus, condylar “neck,” and condyle, even if coronal views are part of the radiographic “package.”

Panoramic images are a better choice (than “plain films”) to determine the overall extent of the injury, particularly when fractures of the posterior segment are suspected. The status of the alveolar crest and the dentition, including the third molars at the angle, is added as a bonus. The symphysis is often “bleached out” by panoramic radiograph, and the study is then of minimal aid in determining the presence of symphyseal fracture. This technical artifact is due to distortion of the focal trough as the panoramic cone sweeps across the symphysis from one side to the other.

A panogram may not have sufficient resolution to reveal subtle fracture. The panogram in Fig. 5.25A, by example, suggests that the posterior segment is without injury. Yet,

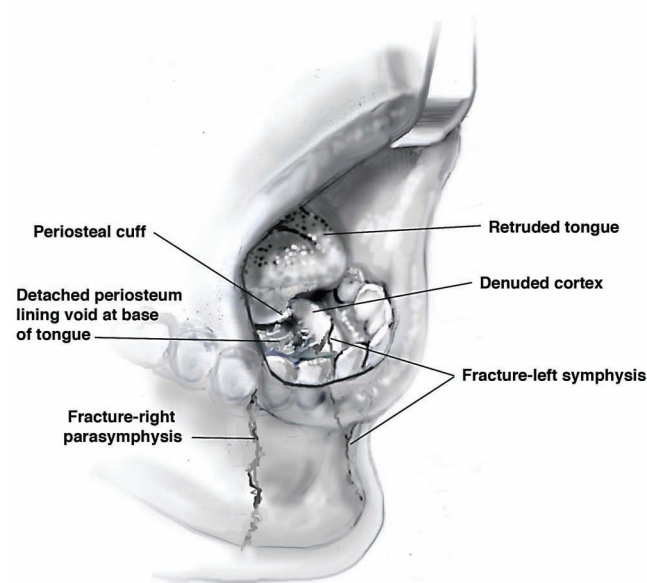


Fig. 5.24

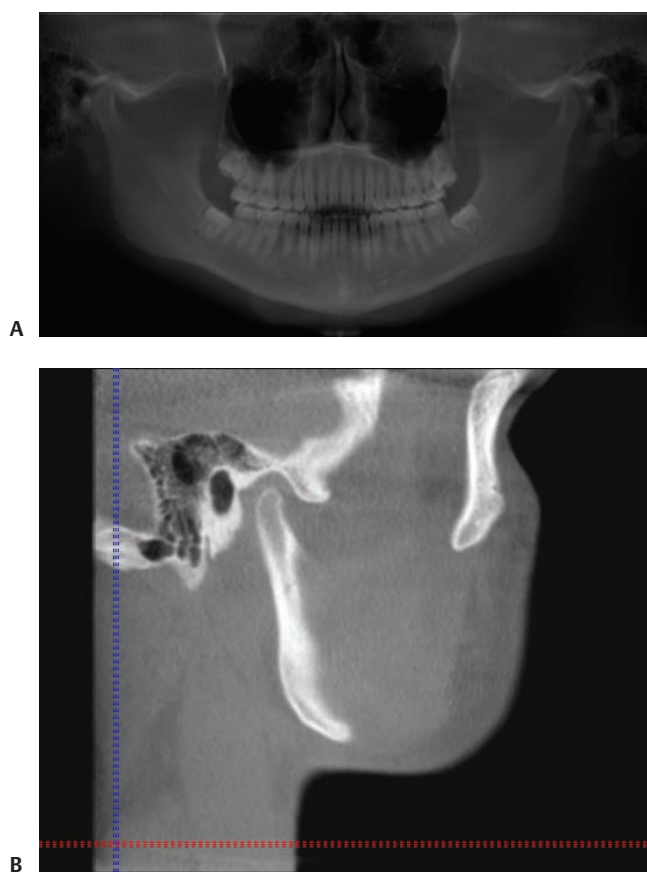


Fig. 5.25 (A, B)

cone beam computed tomography (CBCT), achieved in the same patient, clearly reveals a subcondylar fracture (Fig. 5.25B).

In addition to higher resolution, CBCT avoids mesial “bleaching artifacts” in the area of the symphysis and parasymphysis. Only moderate radiation follows CBCT use because a low-energy anode tube rotates around the patient only once.⁴³

Condylar dislocation out of the glenoid fossa may be anterior, posterior, medial, or lateral. Anterior and anterolateral dislocations of the condyles, often with associated fractures of the anterior segment, are relatively common.^{44,45} Medial and anteromedial dislocations of the condyles are less common. The condyle typically is displaced anterior to the articular eminence but generally remains within the confines of the joint capsule.

Forces directed superiorly toward the center of the glenoid fossa may displace an intact condyle into the middle fossa,⁴¹ as previously noted. If load forces drive the condyle *posteriorly*, the condyle, external (osseous) canal, and tympanic plate may be fractured,^{45,46} creating a cascade of injury (Fig. 5.26).

Arthroscopic observation and magnetic resonance imaging (MRI) demonstrates *disc displacement*, *capsular tear*,

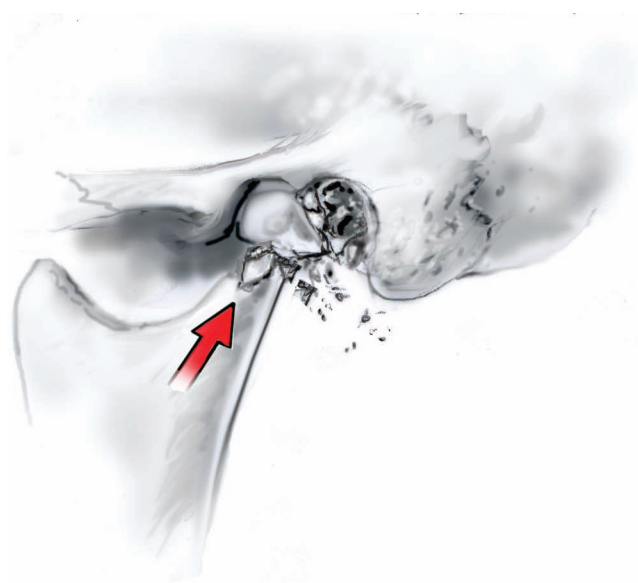


Fig. 5.26

and joint *hemarthroses* in a large number of cases after condylar and subcondylar fracture.^{47–50} And, the extent of these soft-tissue injuries appears to be in direct proportion to the degree of condylar fracture.⁵¹ Simply, more fracture begets more soft-tissue injury nearby.

The disc is seldom injured,^{49,50} even though the disc is usually displaced in the same direction as the fractured condyle, but the disc is seldom displaced from the confines of the glenoid fossa, *per se*.⁴⁹ Injury, rather, is most remarkable in the more mobile tissue, such as the joint capsule and retrodiscal tissue.^{50,52} Greater than two of three patients, for example, demonstrate a rent at the join of the posterior capsule and the retrodiscal tissue on MRI⁵² (Fig. 5.27).



Fig. 5.27

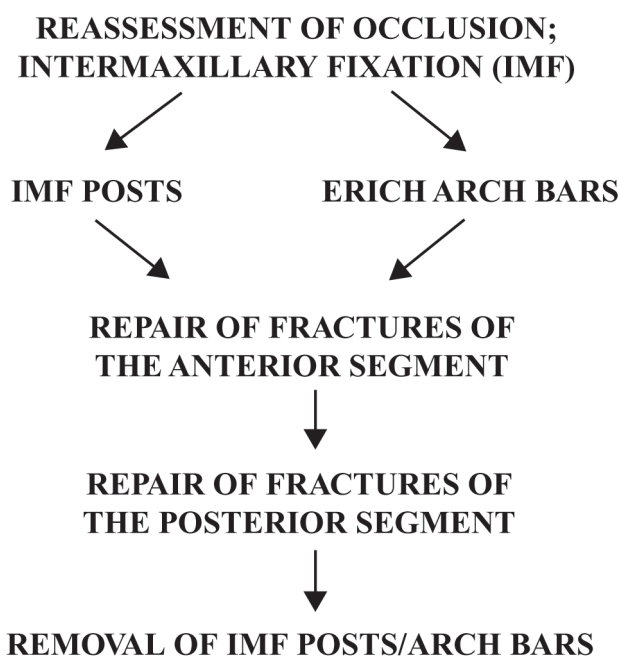


Fig. 5.28

Operative Repair

Algorithm of Repair

Surgery begins with a reassessment of the state of occlusion. The sequence of repair then varies according to the location of the fracture(s), the degree of displacement, and involvement of teeth in the line of injury. In general and with few exceptions, the fractures in the anterior segment (teeth-bearing regions) are repaired before those of the angle, ramus, coronoid, and condyle. Lingual version of the tooth-bearing segments is corrected before reducing fractures of the posterior segment (Fig. 5.28).

The goal of repair is to restore the trajectories of the mandible and thus load-bearing pathways. Stress of mastication can then be referred from the repaired lower jaw to and from the lateral base of the cranium through the glenoid fossa, the alveolus of the upper jaw, the palatal platform, the midfacial buttresses, and the central base of the cranial vault.

Incisions and Prealignment

The jaws are first placed in IMF. In the presence of normocclusion, IMF posts are usually adequate (see Fig. 5.13C). In the presence of malocclusion, crowding of teeth, significantly abnormal wear facets, and multiple fractures, Erich (lugged) arch bars are preferred,⁵³ despite their potential bias (see Fig. 5.14). One of five basic incisions are chosen in the repair mandibular fractures (Fig. 5.29).



Fig. 5.29

Region of the Symphysis and Parasymphysis

The *lower gingivobuccal sulcus (vestibular) incision*, when chosen as one of two options, is achieved with needle electrocautery and moderate current after insertion of Goelet retractors at each commissure to protect the lips. Care is taken to preserve a generous cuff of gingiva for subsequent closure and scarless restoration of the vestibule.

The periosteum over the outer cortex of the mandible is elevated with a sharp Molt #9, beginning at the midline. As the elevation is taken more laterally, the surgeon becomes aware of exiting branches of the mental nerve (Fig. 5.30).

Prealignment is considered after manipulation and reduction of the fragments. Two apertures are drilled through the bone near the fracture line, and 24-gauge wire is used to prealign the inferior margin. Definitive stabilization of the mandible follows, with a bicortical plate (in which screws engage the inner and outer cortex) at the inferior margin and a monocortical plate as a tension band at the midaspect of the outer cortex.

Extremely dislocated fragments in the area of the symphysis and parasymphysis are better approached through an *external incision* (an option other than the gingivobuccal). Prealignment wire and then lag screws or external appliances are more readily applied. An incision in the lower vestibule is best avoided in patients with *degloving injuries* of the floor of the mouth and intraoral exposure of the inner cortex of the mandible. The blood supply to the outer cortex, the vestibule, and the lower lip in these cases is more certainly preserved by an external incision when open reduction is chosen.²⁸

The external incision is marked with surgical ink (methylene blue) and made some 4.5 cm in length,

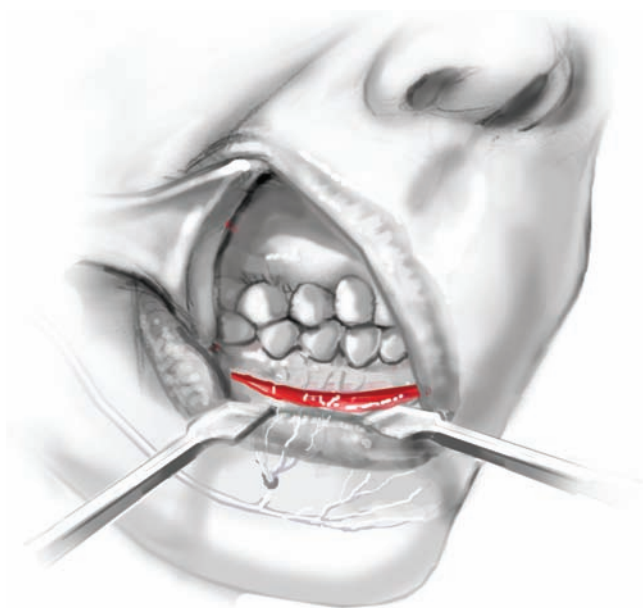


Fig. 5.30

approximately 2.0 cm behind the chin. The center of the incision logically corresponds to the site of fracture at the inferior margin of the mandible.²⁴ The incision is made through skin and subcutaneous tissue using a scalpel. The platysma muscle is undermined with blunt (Gore) scissors prior to dividing the muscle with needle electrocautery (at a moderate setting) to protect the marginal branch of the facial nerve beneath. Meticulous electrocoagulation of vessels gives adequate hemostasis and may speed exposure of the fracture. The fracture is often obliquely positioned and can be palpated as it is approached.

The fragments are prealigned with 25-gauge wire near the inferior margin. The wire-and-knot assembly is placed below the inferior margin, after “outside-in” passage of the wire, so that the wire does not interfere with subsequent application of a locking plate and insertion of bicortical locking screws (see Chapter 3). The first screw is non-locking to better adapt the plate to the bone (**Fig. 5.31A,B**).

A second, less rigid plate may be placed at the midaspect of the mandible as previously noted; screws in this instance are limited to the outer cortex to protect the underlying dentition and neurovascular bundle. Copious irrigation strategically precedes wound closure, as at other sites of mandibular repair.

In the case of the gingivobuccal incision, a running locking horizontal mattress suture with full purchase of the gingiva is usually adequate. We have found an X-1 (large half-circle) needle to be efficient. In the case of an external incision, layered closure is achieved. The incised end of the anterior belly of the digastric is reattached, the periosteum anatomically repositioned, and platysma muscle repaired. Everting subcuticular closure is then consummated.

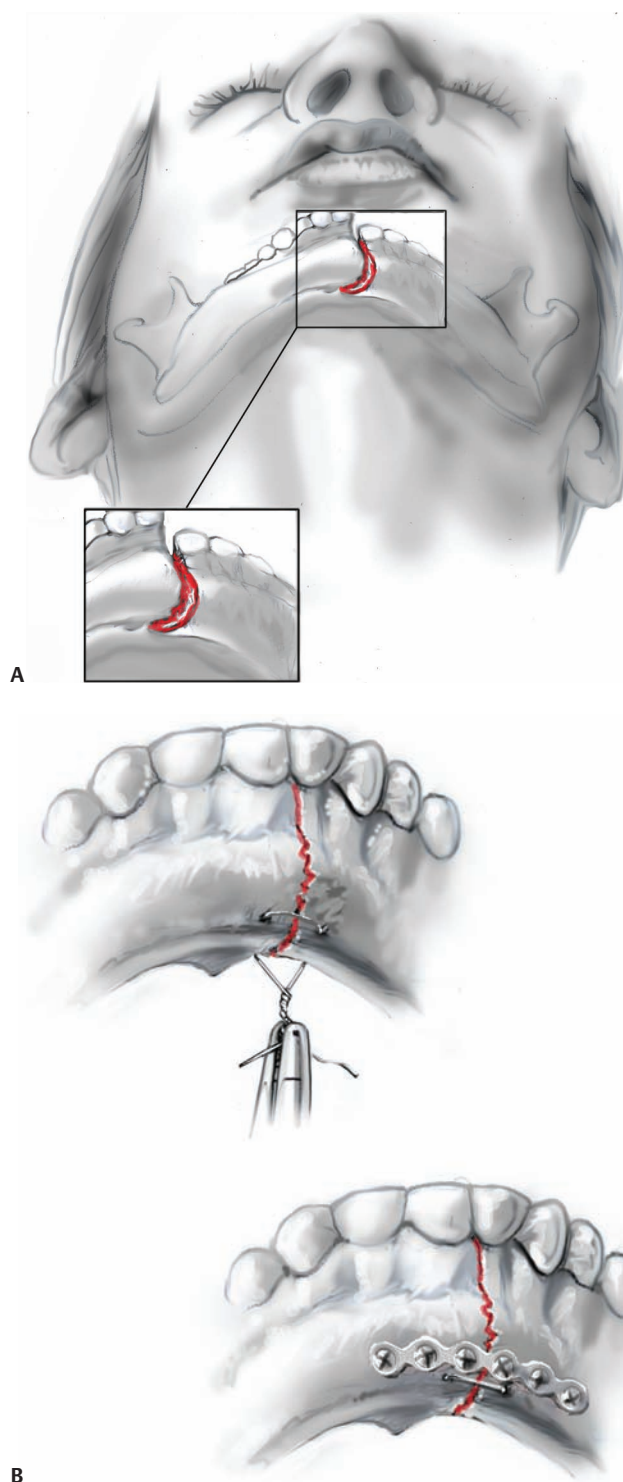


Fig. 5.31 (A, B)

In those instances with oral degloving and mandibular fractures (usually bilateral symphyseal fractures), the intraoral void is closed in one of two ways after copious irrigation. Drains in the symphyseal area usually are not necessary (**Fig. 5.32A,B**).

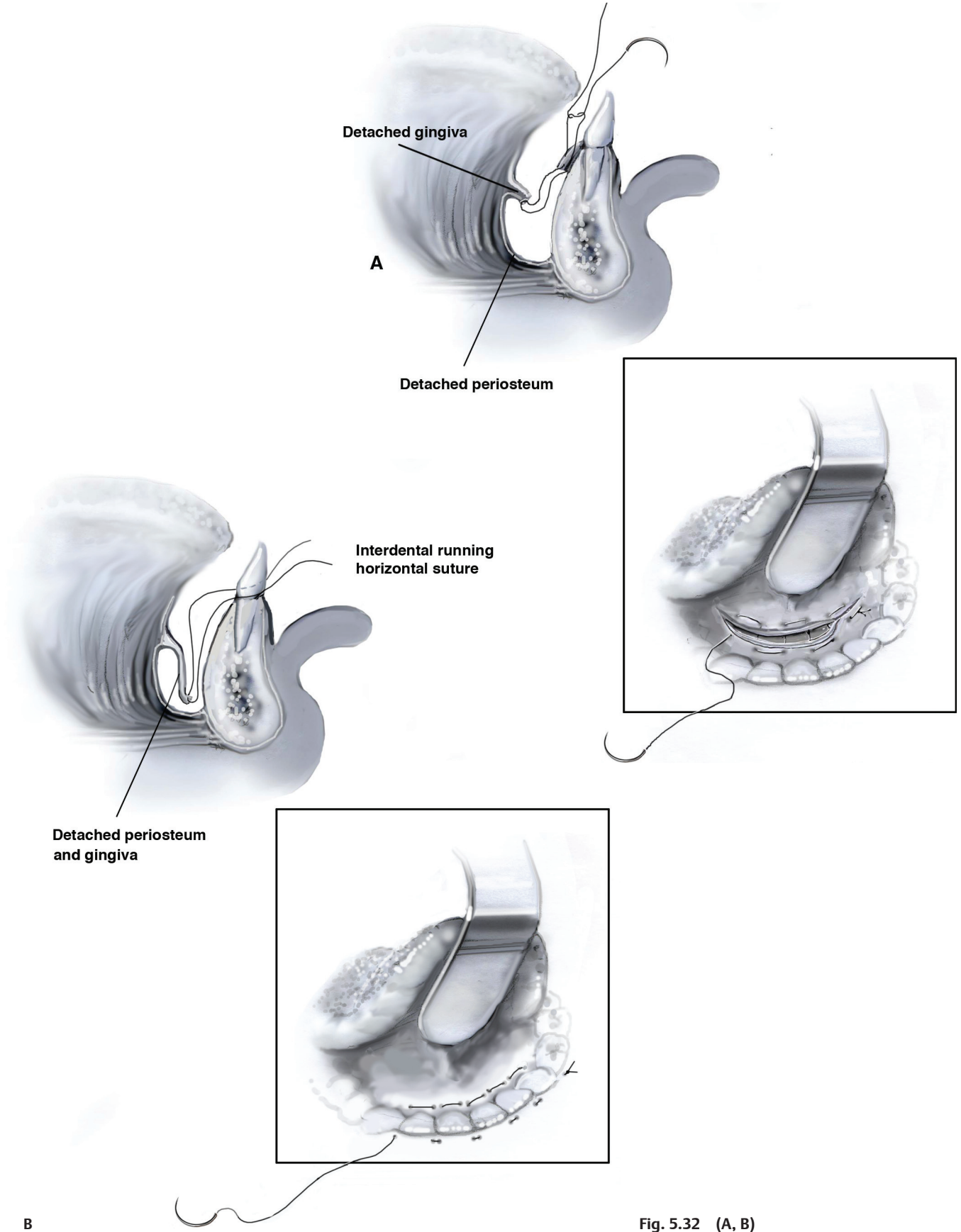


Fig. 5.32 (A, B)



Fig. 5.33

Region of the Body

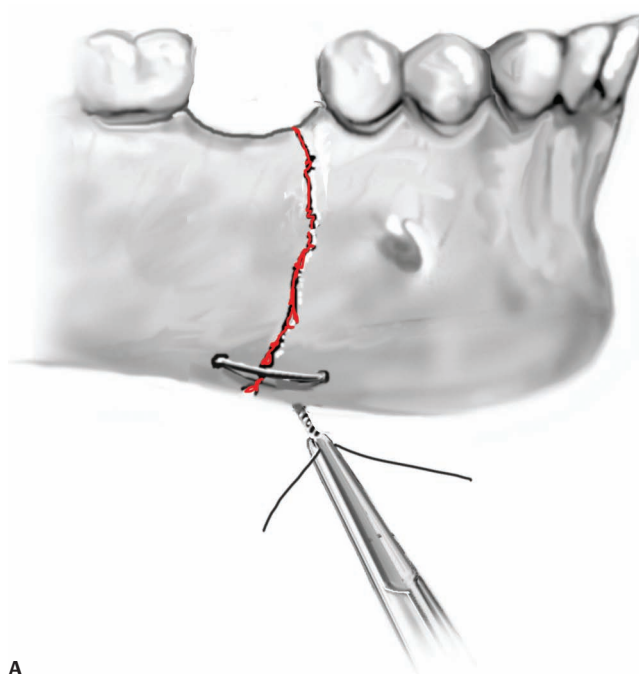
A line is drawn with surgical dye 1.5 to 2.0 cm below and parallel to the inferior margin of the mandible. The incision is achieved with a scalpel and carried through the platysma muscle. The platysma muscle is undermined with blunt (Gore) scissors prior to dividing the muscle with needle electrocautery (at a moderate setting), to protect the mandibular branch of the facial nerve and the facial vein and artery deep to the muscle, over the palpable fracture of the midsection of the body. The vessels are ligated and the *mandibularis nerve* is retracted upwardly to avoid paresis in the postoperative period (Fig. 5.33).

Sharp Molt #9 periosteal elevators are used to elevate the periosteum from the bone at the fracture site. Prealignment is achieved with 25-gauge wire, with care being taken to place the knot below the margin to facilitate eventual placement of plates and screws. The wire may then be removed or left in situ.

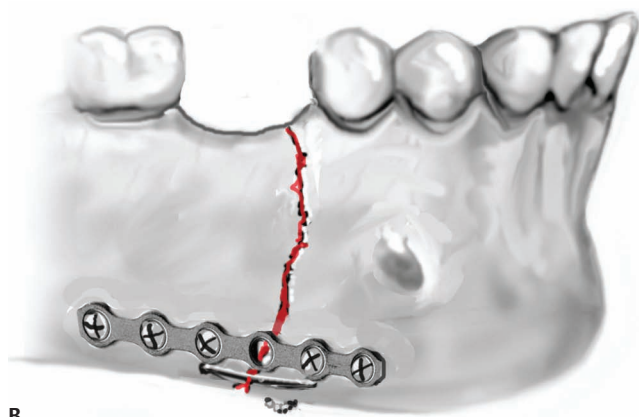
The periosteum (and mylohyoid muscle) are reapposed with resorbable suture. As emphasized by Dingman and Natvig, accuracy in replacement of the periosteum, musculature, and subcutaneous tissue avoids scar adhesion.²⁴ The skin is best approximated with everting techniques. Sutures are removed within 5 days, and rayon-reinforced strips are applied for an ensuing 7 days (Fig. 5.34A,B).

Region of the Alveolar Process

Fractures of the alveolar process most often respond to the application of orthodontic brackets. The brackets are applied to the teeth of involved and adjacent segments, then with a single wire and intermittent ligatures. In more



A



B

Fig. 5.34 (A, B)

distal injuries, banding of the molars is added as a necessary adjunct.

Region of the Angle

Fractures of the angle that require modest manipulation can be successfully managed through an intraoral approach in the retrotrigone area in a large number of cases, when compliance is not an issue.⁵⁴⁻⁵⁶ The external oblique ridge may on occasion be blunted slightly by cutting burrs to accommodate contouring and placement of a five- or six-hole plate with monocortical screws, when this approach is elected. A trochar is seldom needed. Outcomes are good in the carefully selected patient,^{55,56} particularly when a small mini-locking plate is used (Fig. 5.35). A soft



Fig. 5.35

diet is advised for several weeks. When the fracture is unfavorable, multiple, or requires considerable manipulation, the retrotrigone approach to fixation is a poor choice. Better, in these circumstances, is the use of the external (Risdon) incision.⁵⁷ The latter is curvilinear and follows a natural wrinkle some 2.0 cm below and parallel to the inferior margin of the mandible. The platysma muscle is undermined with blunt (Gore) scissors, to protect the marginal mandibular branch of the facial nerve, before cutting the muscle.

The proximal fragment (the ramus) is displaced medially in most cases by muscle action, and so the mesial edge (the angle) is readily palpated as the fracture site is approached. The mandibular branch of the facial nerve is close at hand and is preserved; it is encountered in some one in five cases. The patient is best forewarned of possible injury before surgery despite the use of a nerve stimulator.

A tooth in the line of fracture may be encountered but often can be preserved. The retained tooth tends to buttress the reduction and stabilization, achieved by application of plates and screws. When a tooth interferes with the reduction, the tooth is removed.^{24,26,58}

To gain access to a fracture in the region of the angle, the masseter muscle is incised at the inferior border of the mandible (**Fig. 5.36** [top panel]). Over the roughened,

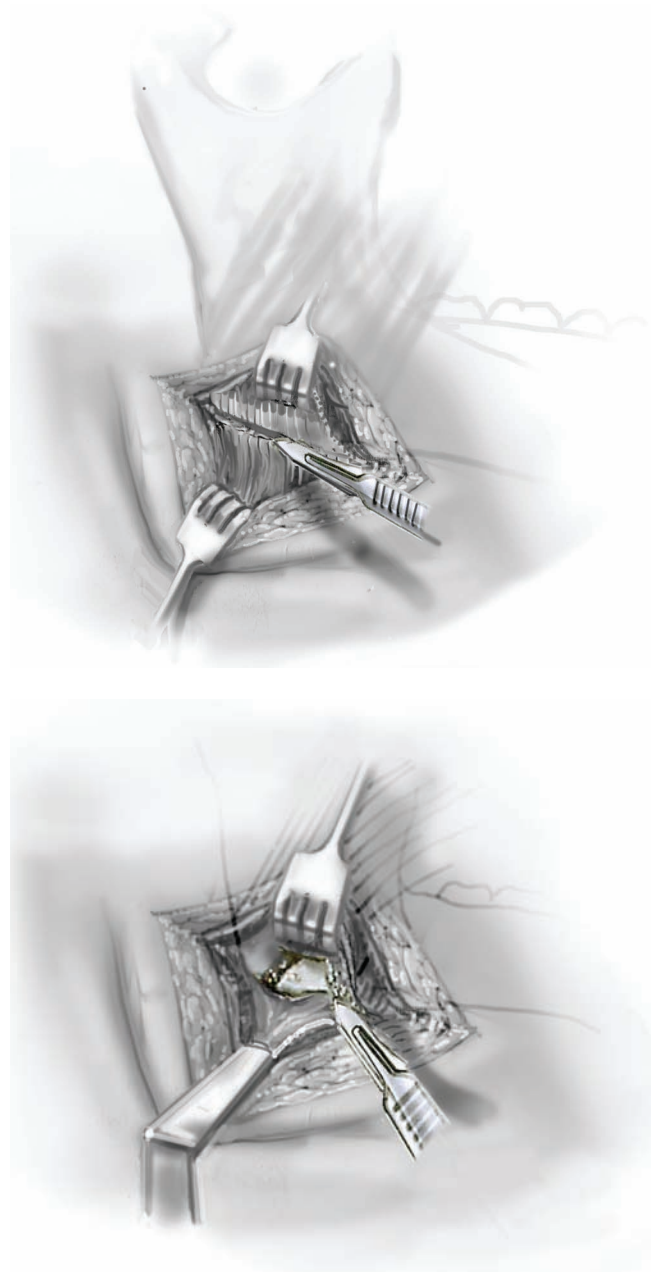


Fig. 5.36

outer cortex of the angle, the masseter attachments insert directly onto bone. These attachments resist elevation until divided by a scalpel^{24,59} (**Fig. 5.36** [bottom]).

Sharp Molt #9 elevators separate the periosteum from the bone of the lateral and medial surfaces of the mandible adjacent to the fracture. The dissection simplifies control of the fragments with Dingman forceps and provides access for the drilling of bicortical holes.²⁴ The ramus, if displaced superiorly and medially, may be difficult to reduce; in this setting, we prefer to place a traction wire to nudge the ramus into alignment. The bone may also be grasped on each

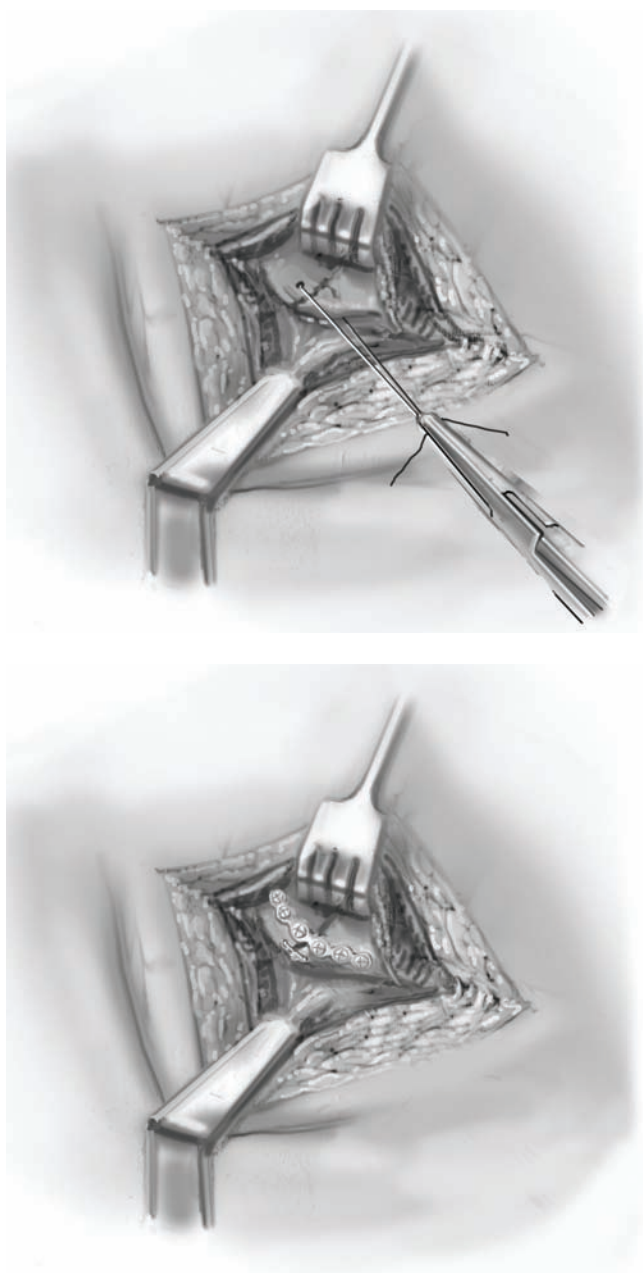


Fig. 5.37

side of the fracture with Dingman bone forceps or large Kocher clamps, and the fragments manipulated.

Prealignment is then achieved by the passage of 25-gauge wire; the wire is drawn securely against the bone using wire-twisting forceps (Corwin), twisted, and then tucked beneath the mandibular margin (not shown). A 2.0-mm locking plate is readily applied to the outer cortex with screws that pass through both the outer and the inner cortex. The first screw is non-locking to favor adaptation of the plate to the bone surface. A second, less rigid appliance may be applied midway between the inferior margin and the alveolus with monocortical screws (**Fig. 5.37**).

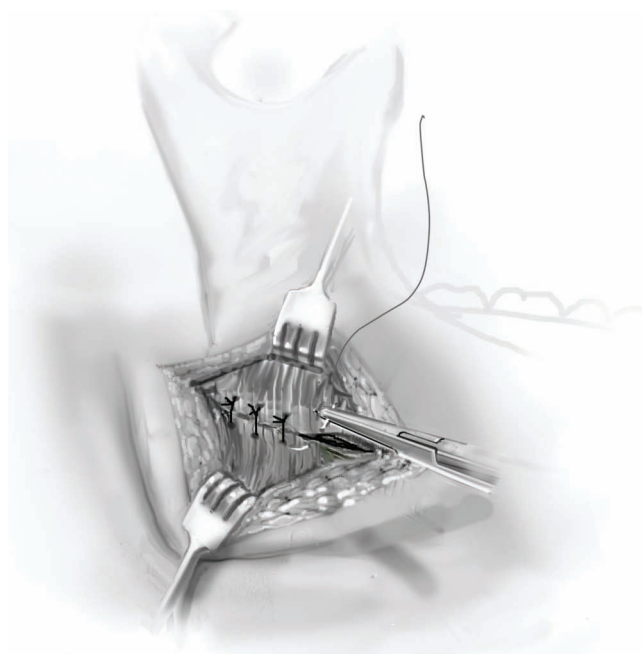


Fig. 5.38

The wire used in prealignment can be removed once stabilization is complete. Copious irrigation follows. A small penrose drain is placed in contact with the bone, prior to closure.²⁴

The pterygomasseteric sling, consisting of periosteum, masseter, and medial pterygoid, is recreated by approximating the three with resorbable, monofilament suture. The restoration of the sling ensures proper soft-tissue coverage of the fracture site and contributes to the blood supply of the injured bone²⁴ (**Fig. 5.38**).

The platysma muscle is also repaired. Meticulous subcuticular closure avoids an unsightly scar.

In the presence of *multiple* fractures of the angle, the posterior segment tends to splay outwardly, and the anterior segment cants toward the tongue. A fracture of the symphysis or parasymphysis, coupled with a fracture of the angle or the subcondylar region, tends in particular to create lingual version of the teeth-bearing segments and ramal splaying. Appropriate reduction and stabilization in these circumstances is favored by the following:

- IMF
- Repair of the anterior (teeth-bearing) segment first (by example the symphyseal, parasymphyseal, or body fracture as the initial repair, and the angle as the second)
- Manual counter pressure in the regions of the angle and the condyles while reducing the fracture in the anterior segment⁵⁷
- The application of a longer plate than usual across the fracture

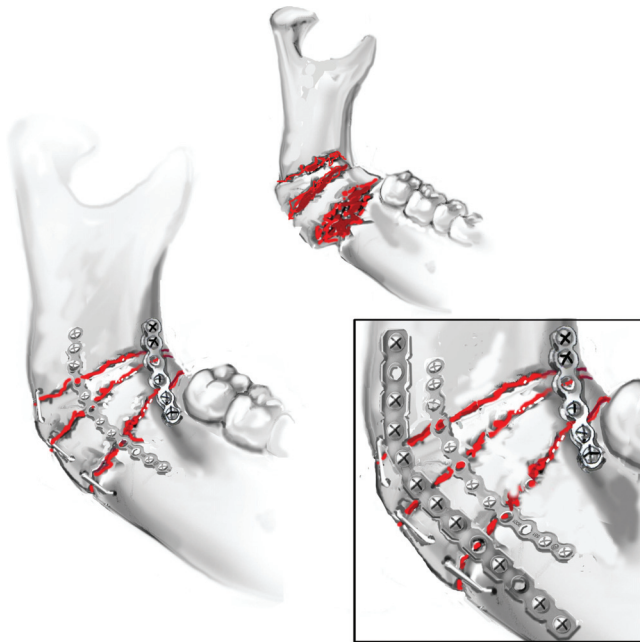


Fig. 5.39

- Wire, a monocortical “guide screw,” or small plates may be used to preassemble the fragments before a rigid appliance is applied
- Prealignment of the bone fragments (creating a larger aggregate of comminuted fragments) begins superiorly and proceeds inferiorly until the margin of the mandible is reached, where a “locking” plate is applied (Fig. 5.39).

Region of the Ramus

Fractures of the vertical posterior segment are exposed in the same manner as fractures of the angle and again require a wire traction suture to control the ramal segment. The fracture fault typically descends obliquely from the coronoid notch to reach the posterior margin of the ramus. Placement of a periosteal elevator beneath the mandible and under the periosteum stabilizes the fracture segments, thus also aiding reduction of the fracture. The retromandibular vein or a branch of the internal maxillary artery may create troublesome hemorrhage unless dissection about the inner cortex is performed with care, including placement of a prealignment with 25-gauge wire.

An 8-hole or 10-hole T-shaped plate or “ladder” matrix appliance bridges the fracture line. The more proximal screws may be inserted first; the upper fragment, with the plate applied, can then be used as a “joystick assembly” to aid alignment of the fracture. A traction wire in the proximal segment may serve the same role. Prealignment with wire also may have benefit before applying an appliance. Screws near the margin are bicortical, and those that are non-marginal are often monocortical (Fig. 5.40).

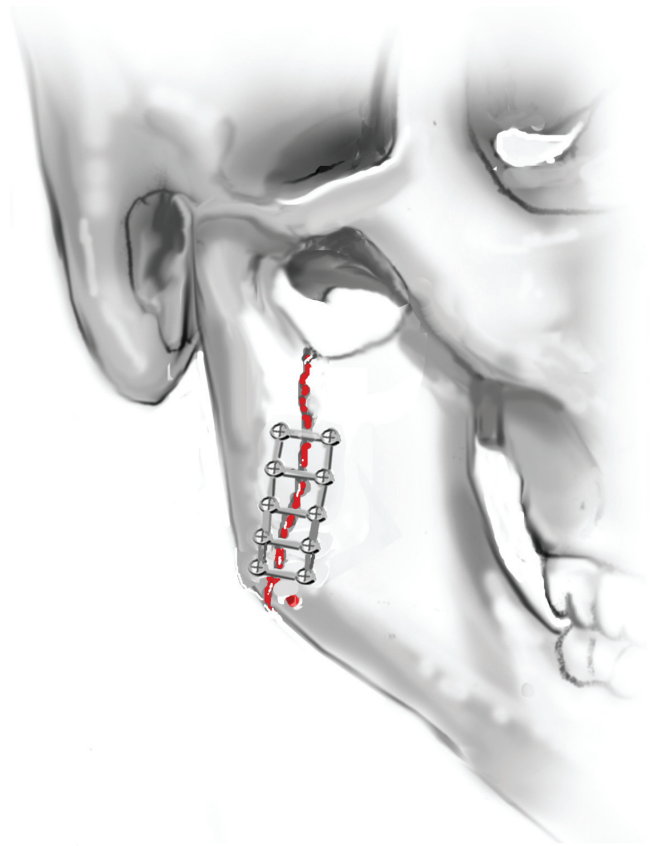


Fig. 5.40

Region of the Subcondylar Process

Studies by Schubert, Kobienia, and Pollock^{4,5} demonstrate the progressive reduction of the total cross-sectional area of the *posterior* segment, from the distal angle and ramus to the coronoid and condyle. It is logical and prescient, then, that the *higher* the level of fracture, the *lower* the chance of one *or all* of the following: successful operative intervention, the opportunity for rigid fixation, callous-free union, postoperative stability, and long-term normocclusion.

Closed treatment, including guiding elastics and compliant, tightly monitored physiotherapy, is the most widely accepted method of management of fractures of the upper region of the posterior segment, even if the condylar fracture is dislocated and oblique and notably if comminution is present.^{24,60–64} (Fig. 5.41).

Yet, *it seems intuitive that direct vision would render greater ease of reduction and more rigid stabilization*. Surgeons continue to explore a surgical solution, girded by the fact that anatomic reduction is often difficult to consummate with closed methodologies, compared with that achieved by open surgical management,⁶⁵ and functional (occlusal) results are not as good after closed techniques as those that follow open reduction.⁶⁶



Fig. 5.41

Most surgeons, nevertheless, choose open reduction with cautious circumspection because of the possibility of untoward preauricular scar, salivary fistula, or transient, or indeed permanent, facial nerve paresis.^{62,67–72} These persistent risks have driven most surgeons to resurrect tenets first established by Zide in 2001 that limit open surgical intervention to 1) cases with extreme dislocation and a significant, intact proximal segment (2.0 to 2.5 cm), and 2) those with instability of ramus height.⁷³ Zide's untemerarious, guarded guidelines also appear to be supported by recent univariate analysis by Lee and colleagues.⁷⁴

An answer allowing one to both “have the cake and eat it too”⁷⁵ may lie in endoscopic exposure and repair. Miloro⁷⁶ and Kellman⁷⁷ report positive experience in early cohorts of patients using external neck (Risdon) and intraoral incisions, respectively. Other studies are under way at several centers assessing outcomes using endoscopically assisted miniplate fixation through a limited transoral incision.⁶⁵ One preliminary report defines experience through 2009, using a randomized approach to patient selection.⁷⁸ These investigations and those by Lee⁷⁹ and by others seem to portend more precise selection of surgical candidates⁷⁴ and greater use of endoscopic approaches over time.

Approach to Collateral Damage

Temporomandibular Joint Syndrome

Temporomandibular joint syndrome (temporomandibular joint dysfunction) may follow jaw, joint, or glenoid fossa injury and require consultation with oral surgery colleagues.

Physiotherapy tenders relief of symptoms of many patients. Surgical intervention is reserved for the special few.

Cervical Spine

Most clinical studies since the mid-20th century have documented *cervical spine fractures* in only 1 to 4% of patients with facial fractures.^{80–86} The low incidence belies its significance because of the high potential for mortality and neurologic morbidity⁸⁷ (**Fig. 5.42**).

Great effort is expended by *serial* clinical examination and radiography to detect occult cervical spinal injury in the triage and emergency setting. The patient is often not released until a radiologist “reading” has documented the absence of fracture or other pathology. A cervical collar may be issued to the patient awaiting secondary consultation with orthopedic or neurosurgical colleagues. Detailed statistical analysis of combined injuries of the face and cervical spine^{85,86} suggest the following when *cervical spine* injury/injuries are present (see Chapter 9):

1. Excessive speed in the absence of restraints is a common presentation.
2. Traditional methods of treating maxillofacial injuries usually merit modification to protect the airway and to handle related issues.
3. Approximately 90% of patients have coexisting mandibular fractures.
4. Approximately 50% have collateral fractures of the maxilla and/or the zygoma.⁸⁵

Pulpal Necrosis After Alveolar Process Fractures

One in ten teeth involved in alveolar process fractures undergo pulpal necrosis in the immediate post-traumatic period or in a deferred manner, months and years after injury. Patients are best forewarned of this possibility that may lead to endodontic intervention.

Edentulous Mandible

The edentulous mandible has neither dentition (particularly molar teeth), unlimited endosteal blood supply,^{17,87} nor a significant alveolar crest to buttress load-forces against lateral impact. Fractures of the edentulous mandible may thus be extensive and/or deserve special-case status, requiring lengthy transperiosteal locking systems, even supplemental bone grafting (**Fig. 5.43**).⁹⁰

Exemplary Repair

Case 5. Mandibular Fractures

This patient experienced bilateral fractures of the mandible (**Fig. 5.44A–D**). Erich arch bars were applied,

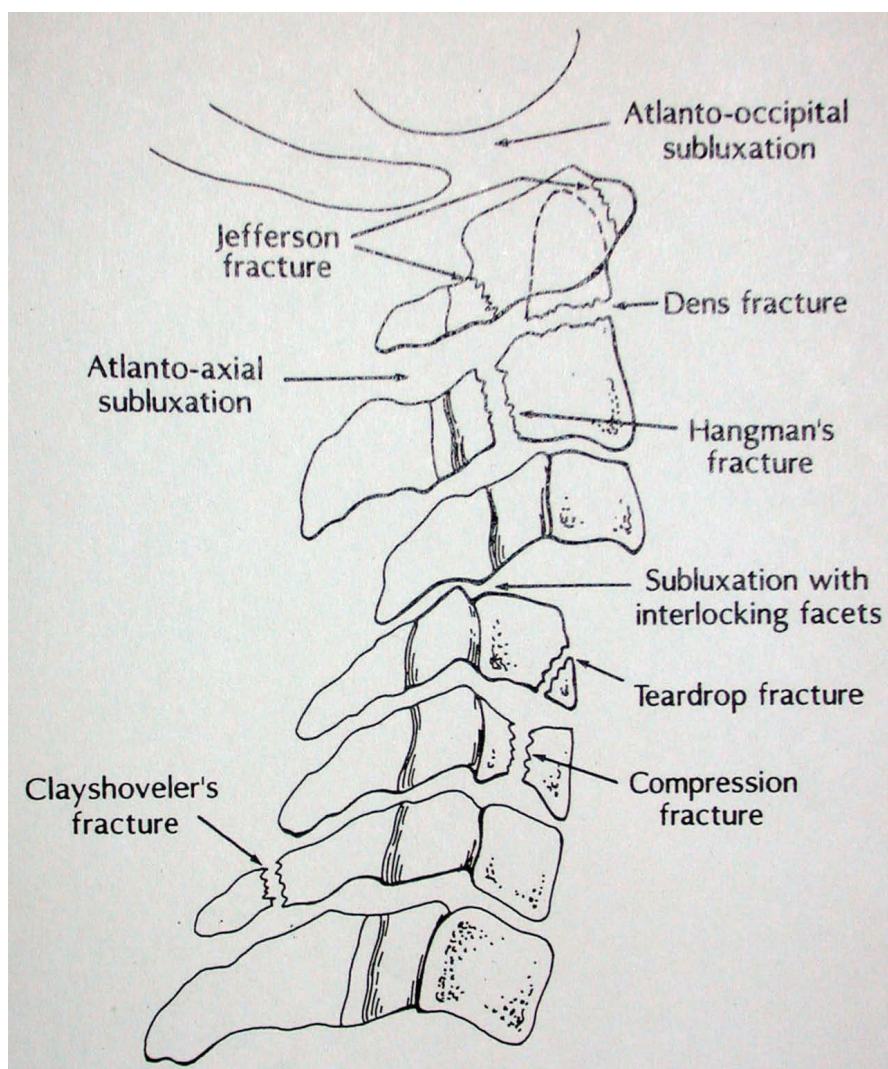


Fig. 5.42



Fig. 5.43



Fig. 5.44 (A-G) (Continued)

and the fracture distal to the right canine was approximated through an incision in the right vestibule. The fragments were stabilized with a rigid plate with bicortical screws. The mental nerve was preserved (Fig. 5.44E-G). Training elastics were used for several

weeks to reduce the subcondylar fracture of the posterior segment. Follow-up is pictured several years after repair (Fig. 5.44H,I). Pretraumatic occlusion was restored, and good return of function was achieved (Fig. 5.44J,K).

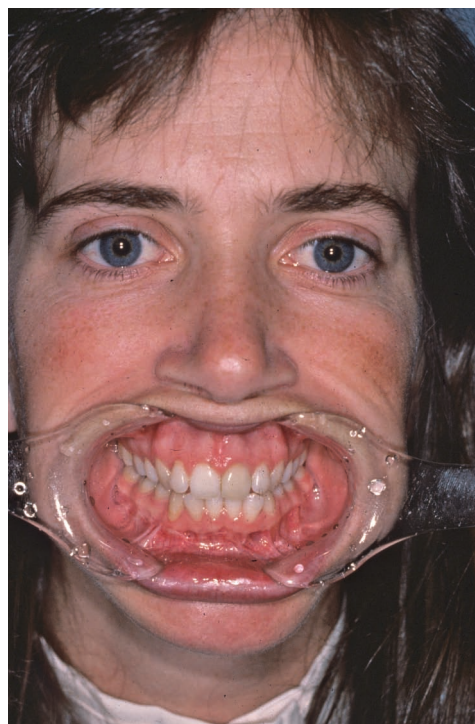


Fig. 5.44 (Continued) (H-K)

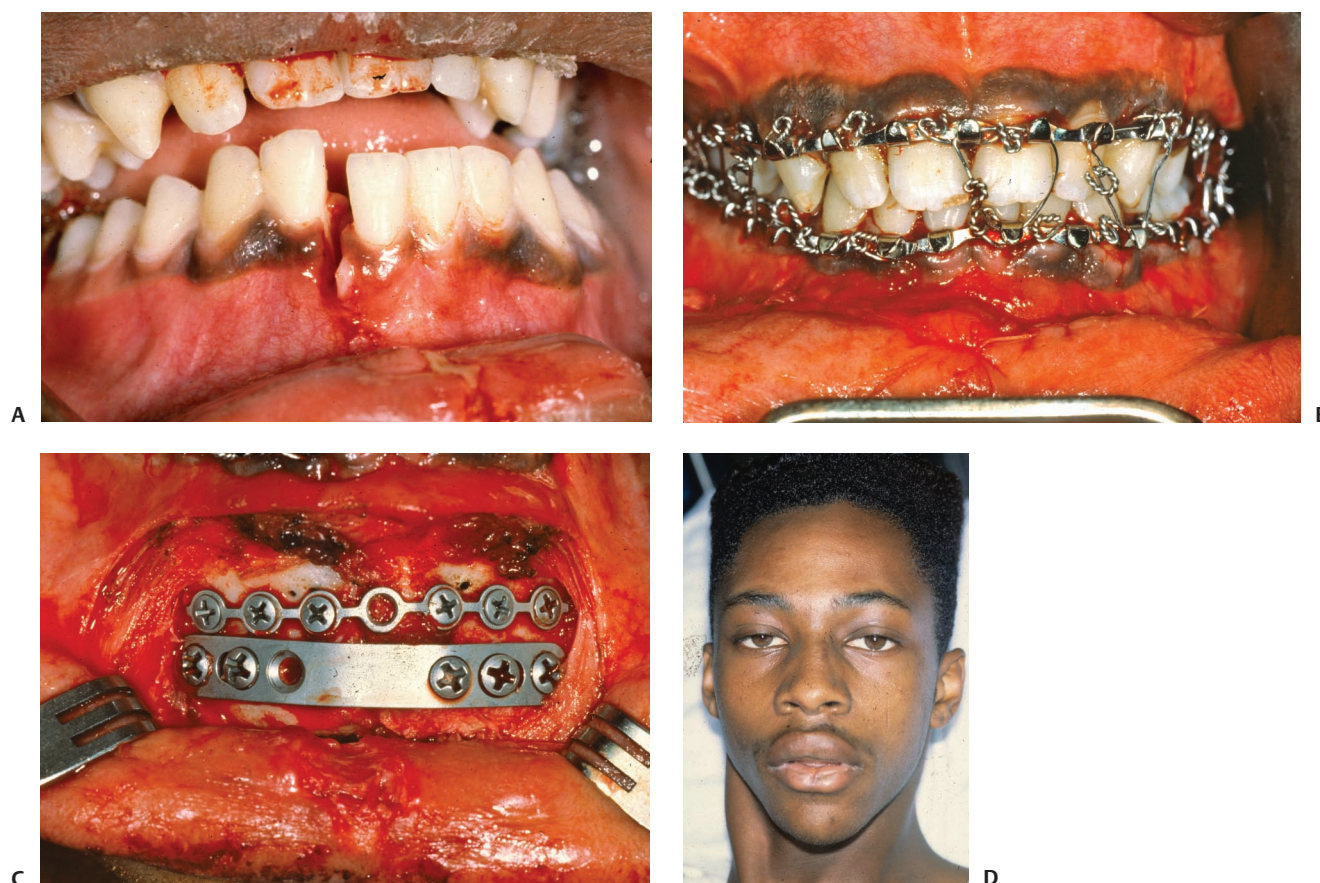


Fig. 5.45 (A-D)

Case 6. Mandibular Fractures

This patient suffered a midline blow to the mandible and sustained bilateral subcondylar fractures and a midline symphyseal fracture. Prealignment of the latter was achieved with wire after IMF. Upper monocortical and a lower bicortical plates were used to stabilize the anterior segment. Note the generous cuff of gingiva for subsequent vestibular wound closure (**Fig. 5.45A-C**).

Guiding elastic traction and physiotherapy were used over several weeks. Follow-up is pictured 1 year following repair (**Fig. 5.45D**).

■ Key Points

The mandible is basically a tubular bone with relative independence from the other components of the craniofacial skeleton. Parabola-like and palate-less, with thickened cortices in its anterior segment, the mandible can be difficult to reduce and stabilize. In the anterior segment, IMF and prealignment are frequent preludes to rigid fixation.

Paradoxically, fractures in the posterior segment (angle, ramus, and subcondylar process) may allow successful reduction with semirigid fixation and intraoral application of monocortical screws, thus defying concepts of rigid fixation.

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6 The Cranial Vault and Cranial Base (Frontal, Sphenoid, Temporal, and Occipital Bones)

■ Part 1. Surgical Anatomy and General Considerations

Five bones (the *frontal*, *ethmoid*, *sphenoid*, *temporal*, and *occipital*) house the central nervous system and constitute the cranial base. Although the architecture of the bone enveloping the brain and brainstem varies greatly, the housing in general is thick, contoured, strongly reinforced, uniquely grained (see Chapter 2), and robust, despite perforation by several foramina¹⁻⁷ (Fig. 6.1A,B).

The Osteology of the Anterior and Middle Cranial Vault (the Frontal, Ethmoid, Sphenoid, and Temporal Bones)

The *frontal bone* has two components, one vertical and the other horizontal, mimicking the L-shaped architecture of the temporal bone. The *vertical component* resembles the hinged, bivalved, cockle shell of shellfish, and thus is referred to as the frontal boss or *squama*.⁷ The *horizontal plate* of the frontal bone (the frontal sinus floor) is shelf-like and the most anterior component of the cranial base. It extends *laterally* to overlie the medial superior orbital roof and *medially* to overlie the anterior ethmoid cells⁷⁻¹¹ (Fig. 6.2A,B).

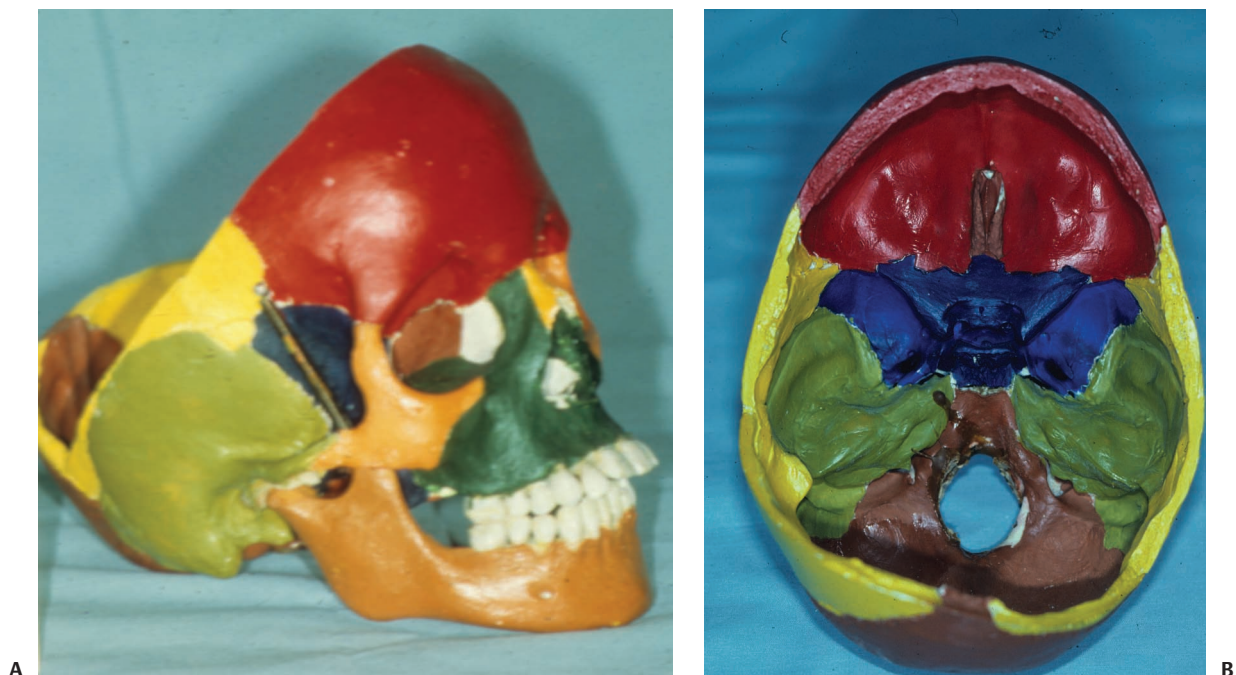


Fig. 6.1 (A, B)

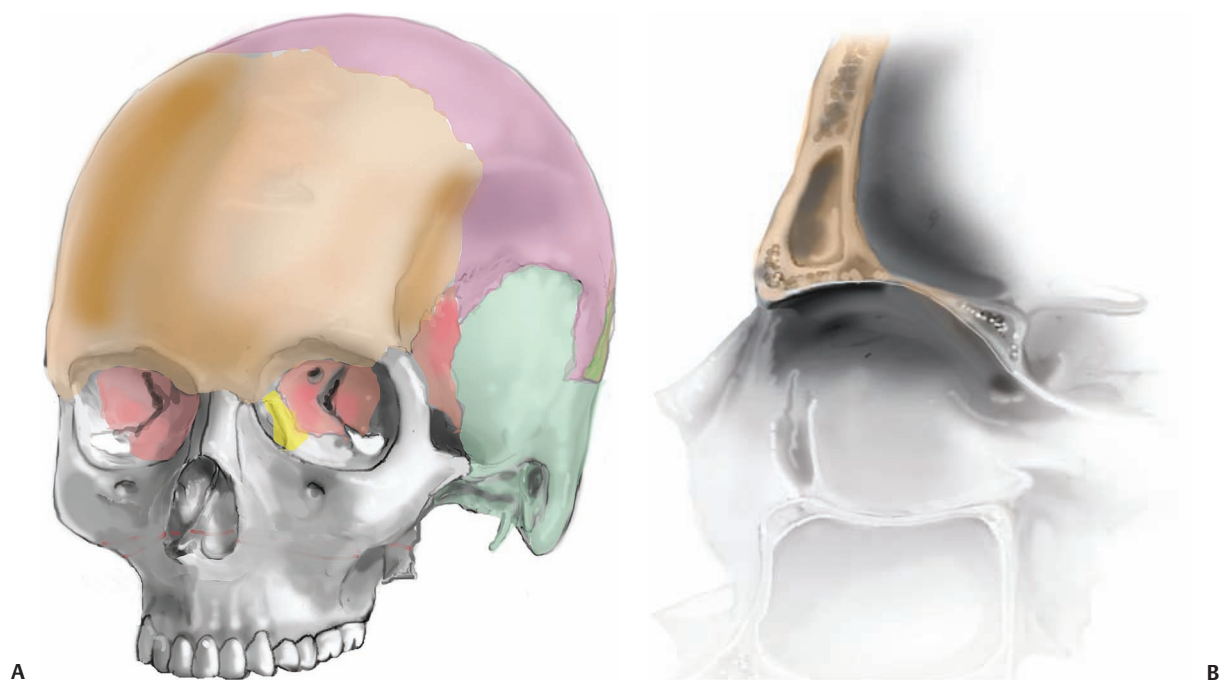


Fig. 6.2 (A, B)

The frontal sinus has its greatest (anterior-posterior) depth in the midline at the level of the *nasofrontal suture*, and its anterior table is thickest at the midline, immediately above the nasofrontal suture.^{6,7,12–14} The frontal sinus floor and the posterior table are only a few millimeters in thickness, thus subject to trauma. The posterior table marks the forward limit of the anterior cranial fossa (skull base) (**Fig. 6.3**).

The brows and superior orbital rims are “surface markers” that suggest the level of the floors of the frontal sinus and the anterior cranial fossa.⁷ The distance from the anterior table to the posterior table is abbreviated. Fractures of the anterior and posterior tables, with overlying lacerations, may therefore create a conduit to the dura and underlying brain. Cerebrospinal fluid (CSF) may be expressed through the open wound.

The frontal bone contributes to the roof of the orbit and the upper medial orbital wall.¹⁵ The roof reaches its nadir approximately 1 cm beyond the supraorbital rim and then gradually descends toward the outlet of the optic canal (see Chapter 8). The orbital roof separates the orbit from the anterior cranial fossa laterally and from the frontal sinus medially^{2,7} (**Fig. 6.4A,B**).

The anterior table, posterior table, and crista galli are pictured. Attachment of the dura in the area of the crista is commonly rent asunder by fractures of the posterior table (**Fig. 6.5**).

Like all *anterior* paranasal sinuses, the frontal sinus has a defined outflow tract, with three components: an infundibulum, an ostium, and a recess.^{16,17}



Fig. 6.3

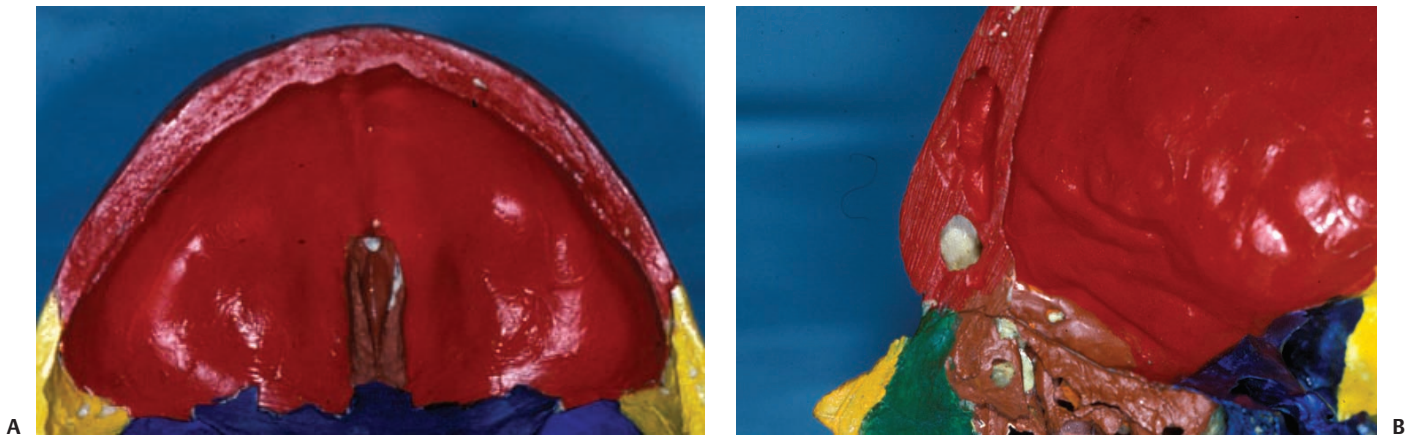


Fig. 6.4 (A, B)

The infundibulum of the *frontal sinus outflow tract* (FSOFT), a funnel-like structure found in the anteromedial floor, is directed posteriorly toward the ostium and nasofrontal recess. It is on a line 8 mm off the midline and directed inwardly only some 8 to 12 mm. The nasofrontal recess (the third component) of the tract is a passive space, created by the *agger nasi* cells anteriorly and the *ethmoid bulla* posteriorly (Fig. 6.6).

The boundaries of the frontal recess are created by surrounding structures such that the term “nasofrontal duct” is a misnomer, and, according to international nomenclature, should be abandoned. A true nasofrontal duct exists in only 5% of patients, each with aberrant anatomy.¹⁴ The infundibulum and the ostium are visible from above in the anterior medial floor at surgery or upon examination of the skull; the frontal recess by comparison is visible only from below with the aid of an intranasal endoscope.



Fig. 6.5

The *ethmoid* bone establishes the greatest depth of the anterior cranial fossa. Housed at its center are the *cribriform plate* (through which the two olfactory tracts pass) and *fovea ethmoidalis*, the roof of the ethmoid (see Chapter 7). The cribriform plate is only 1 mm thick and is delicate compared with the fovea. The fovea progressively thickens away from the midline,¹⁸ much like a miniature palatal platform (see Chapter 4) (Fig. 6.7A).

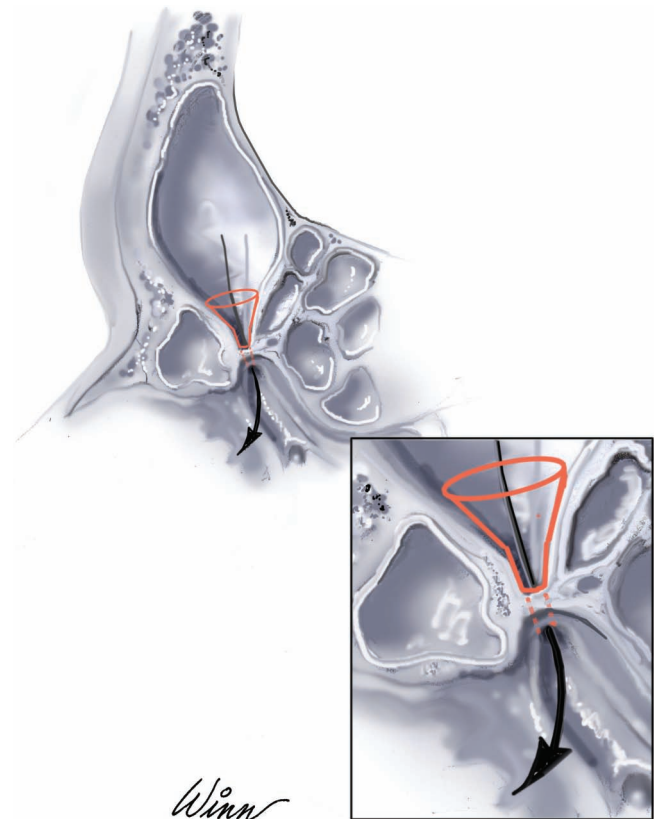


Fig. 6.6

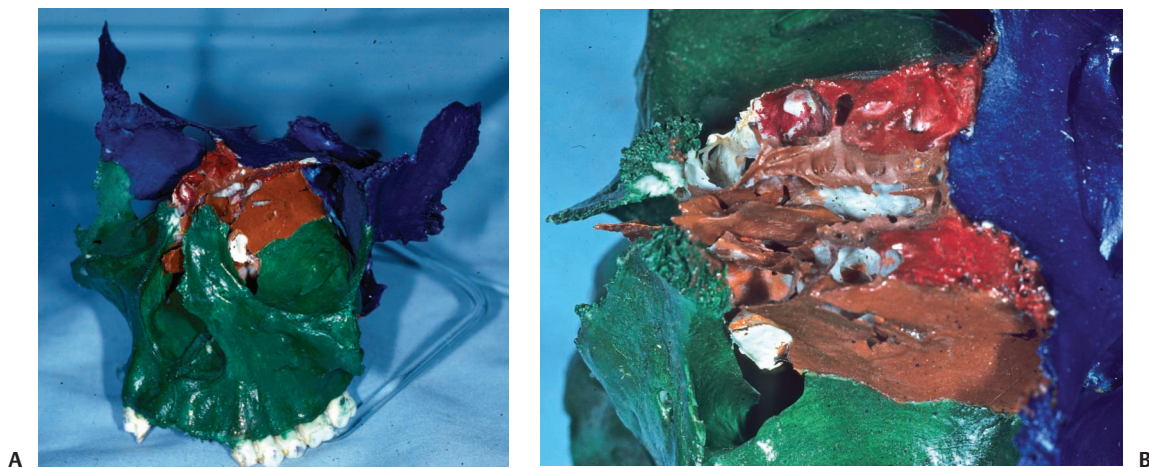


Fig. 6.7 (A, B)

The cribriform plate and fovea are vulnerable to load forces and are readily involved by fractures of the floor of the frontal sinus and the medial orbital frame^{19–26} (**Fig. 6.7B**).

The upwardly contoured orbital roofs (created by the orbital plates of the frontal bone) bear the corrugated stigmata of contact with the *gyri* of the frontal lobe of the brain.⁷

Wedged between the frontal, ethmoid, temporal, and occipital bones is the *sphenoid*, an unusually shaped bone with a body and three pairs of processes: greater wings, lesser wings, and pterygoid processes. The intermediate position of the sphenoid is apparent in lateral and frontal views of the “painted skull” and equally notable when viewed at the cranial base (**Fig. 6.8**). The span and the

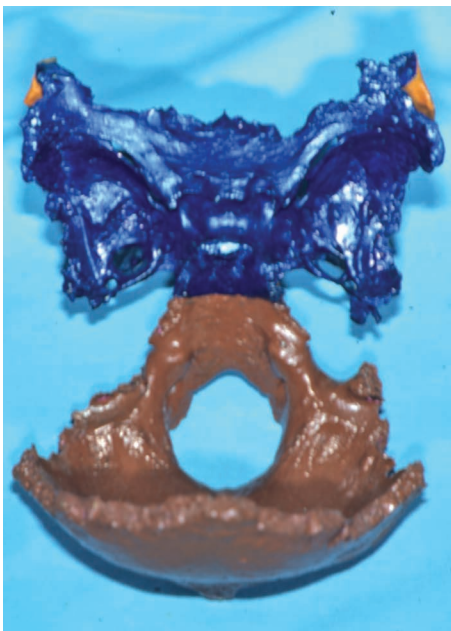


Fig. 6.8

other features of the sphenoid at the cranial base are dramatized in the painted skull.

The sphenoid bone is strategically located and receives load-bearing stresses (*facial force equilibrium circuits*) (see Chapter 2) from multiple areas, notably the following five (**Fig. 6.9**):

- The frontal boss and orbital plates of the frontal bone
- The anterior and posterior maxillary buttresses of the midface, arising from the palatal platform
- The squama and petrous pyramid of the temporal bone
- The condyles of the mandible, by way of the glenoid fossa
- The most anterior portion of the occipital bone

The *planum sphenoidale* and the *anterior clinoid processes* mark the posterior limit of the anterior cranial fossa (anterior skull base).^{6,7} The *planum sphenoidale* is a flattened surface, forming the anterior most portion of the roof of the sphenoid sinus in front of the *sella turcica* (**Fig. 6.10**).

The *planum* connects the two lesser wings of the sphenoid as they arise from the optic strut (see Chapter 8) to create the sphenoid ridge laterally and the anterior clinoid process posteriorly.

The *optic chiasm* resides in a groove just medial to the anterior clinoid process.

The greater wings of the *sphenoid* are elevated centrally to create the *sella turcica* but depressed laterally to accommodate each temporal lobe at a lower plane. The greater wings, in doing so, form the *superior orbital fissure* and define the anterior boundary of the *middle fossa*.

The descent in the floor of the middle fossa puts the pole of the *temporal lobe* behind the thickened, deep lateral wall of the orbit (contributed by the great wing

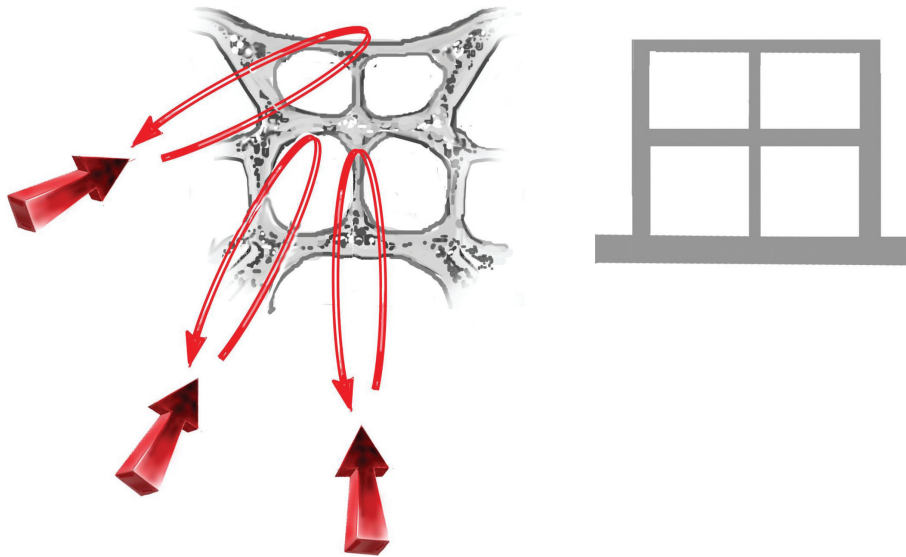


Fig. 6.9

of the sphenoid). Occult temporal lobe contusion is suspected when the deep lateral wall of the orbit is displaced.²⁷

The lateral walls, roof (*planus sphenoidale*), and floor of the sphenoid sinus are thick and robust, as seen in coronal section.^{6,28} The floor forms the roof of the nasal vault (choana) below and is twice the thickness of the bone of the posterior palate, creating, as evident in **Fig. 6.11**, a tiered architecture. The first tier establishes the palatal platform, the sphenoidal platform is some 2 cm directly above, and the roof of the sphenoid sinus is 1 to 1.5 cm further superior.

The sphenoid sinus floor extends laterally to engage the dense base of the petrous pyramid, the squama of the temporal bone, and a small portion of the occipital bone. Structural continuity across the base of the skull, at the level of the sphenoid floor, is broken only by *three*

foramina (foramen ovale, lacerum, and spinosum [OLS]) in the most lateral aspect of the greater wing of the sphenoid (**Fig. 6.12**).

The foramina create an area of structural weakness, just lateral to the lateral wall of the sphenoid sinus. *Frontobasilar, ethmoidosphenoid (basilar), temporal, temporobasilar, and occipitobasilar fractures tend to “track” toward this area*, and the foramina (OLS) serve as “end points.” When front-to-back or side-to-back basilar fractures combine, the faults retain their “rights of passage” through one or more of the foramina.

The posterior boundary of the middle fossa is defined by the clivus and by the petrous ridge bilaterally.^{7,29} The floor (greater wing of the sphenoid) and lateral walls (squama of the temporal bone) of the middle fossa are grooved by the gyri of the temporal lobes and by the *middle meningeal artery* as its frontal and parietal branches course anterolaterally. The frontal branch of the artery ascends

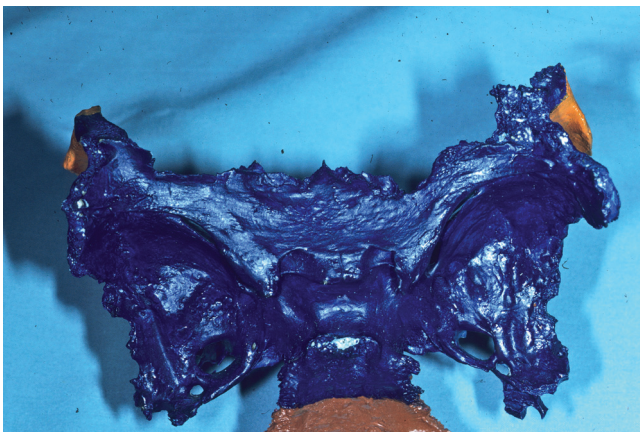


Fig. 6.10

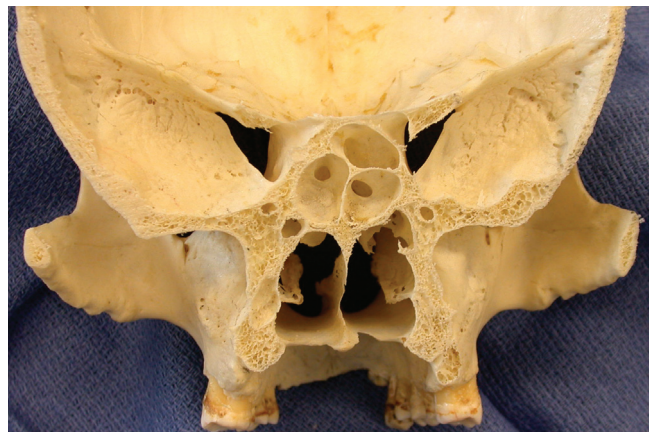


Fig. 6.11

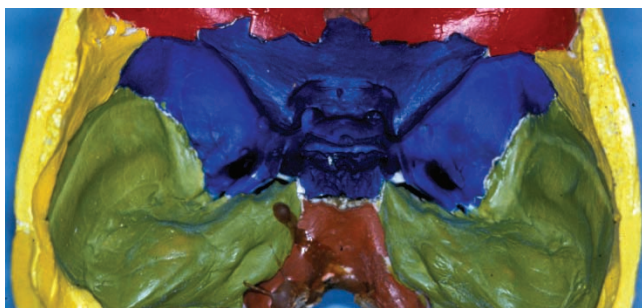


Fig. 6.12

to the lateral extreme of the sphenoid ridge, before turning posteriorly. The turning point of the anterior branch of the *middle meningeal artery*, in terms of surface anatomy, is referred to as the *pterion*, a key landmark some 5.0 cm above the suture of the zygomatic arch, where the coronal, frontal, temporal, and parietal sutures intersect.

Fracture of the relatively thin bone at the pterion may injure the anterior branches of the middle meningeal artery (clinging to the undersurface of the cortex of the pterion) and provoke an *epidural hematoma* (Fig. 6.13).

The *temporal* bones are situated at the sides and base of the skull. Each temporal bone consists of five parts that fuse by the end of the first year of life: the *squama*, *petrous*, *tympanic*, and *mastoid* portions, and the *styloid process*. Based on its pyramidal shape, the petrous segment is called the *petrous pyramid*, with the apex directed inwardly.

The *squama* is L-shaped. Its outer surface is roughened and convex, providing attachment of the temporalis muscle before the muscle descends to attach to the coronoid process. The squama of the temporal bone is not as thick as the *squama* of the frontal and occipital bones (Fig. 6.14).

Projecting forward from the lower portion of the temporal squama is the beginning of a long “arch,” the *zygomatic process* (see Chapter 8). The anterior end is deeply serrated and angles downwardly to engage the upwardly serrated temporal process of the zygomatic bone^{6,7} (see Chapter 8). The *temporal fascia* is attached at the upper border of the arch and the masseter muscle the lower (Fig. 6.15).

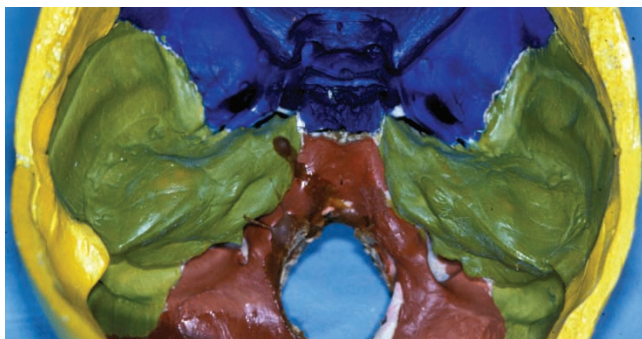


Fig. 6.14

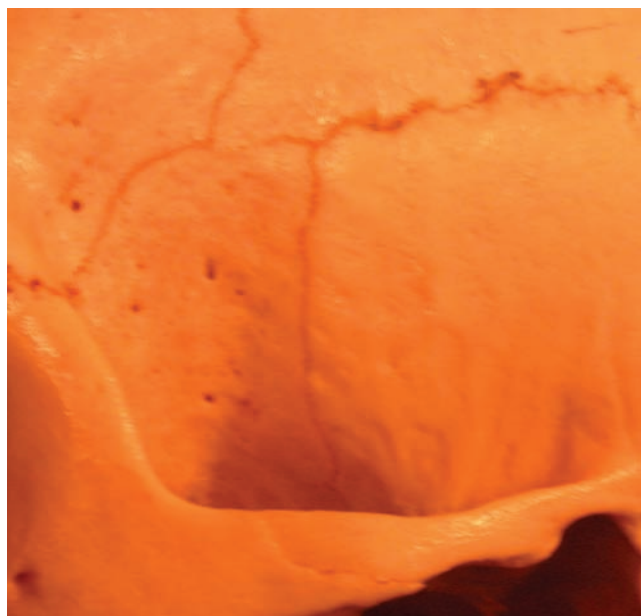


Fig. 6.13



Fig. 6.15



Fig. 6.16

As the *zygomatic process* (of the temporal bone) joins the *temporal process* of the zygoma, it becomes flattened and linear (see Chapter 8). With trauma, the fragments of the arch splay outwardly and may overlap, such that the linear architecture of the arch is replaced by outward bowing (Fig. 6.16).

Upon impact, the body of the zygoma collapses with loss of malar projection and tends in many instances to settle 1) *inferiorly, medially, and posteriorly* or 2) *inferiorly, posteriorly, and outwardly*. Outward and downward displacement expands the orbit; medial and inward

dislocation constricts the orbit and its contents and may provoke rapid intervention. In a structural sense, the zygomatic arch, zygoma, and lateral orbit are to the upper face what the palatal shelves and mandible are to the lower face, as they determine appropriate upper facial width and projection. The goal of surgery is reestablishment of the linearity of the splayed arch and the return of it and the zygoma to their anatomic position (Figs. 6.17 and 6.18).

“Trimanual reduction” is best achieved with an elevator (through a small incision in the maxillary vestibule) while manual pressure is applied over the central aspect of the arch by a surgical assistant. Rigid fixation is required in the presence of instability, but exposure (of the arch) is provided by a coronal incision (see Chapter 3).

The posterior end of the zygomatic process is anchored by two roots, the *anterior* and the *posterior* roots. The *posterior root* is sharply chiseled as it curves backward and upward in continuity with the *temporal line* that defines the attachment of the origin of the temporalis muscle. The posterior root passes inferiorly to contribute to the lateral osseous aspect of the external auditory canal. Fractures of the posterior root and external canal may extend to the lateral aspect of the mastoid and trigger hemorrhage in the region (Fig. 6.19).

The broad, strong *anterior root* of the zygomatic process ends abruptly in a rounded, cartilage-covered eminence, the *articular tubercle*.⁷ The tubercle forms the front

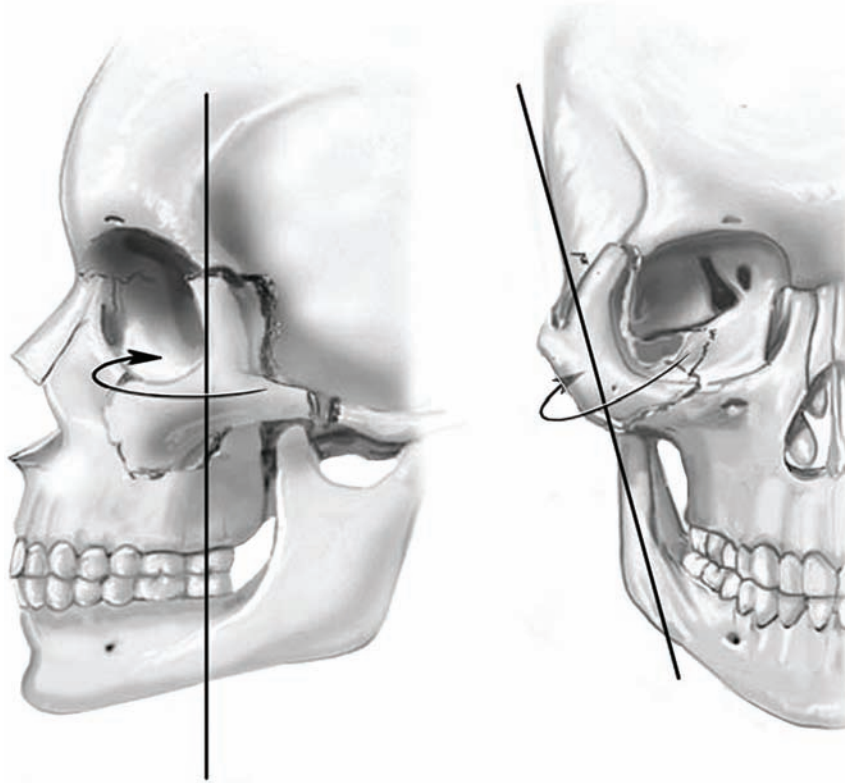


Fig. 6.17

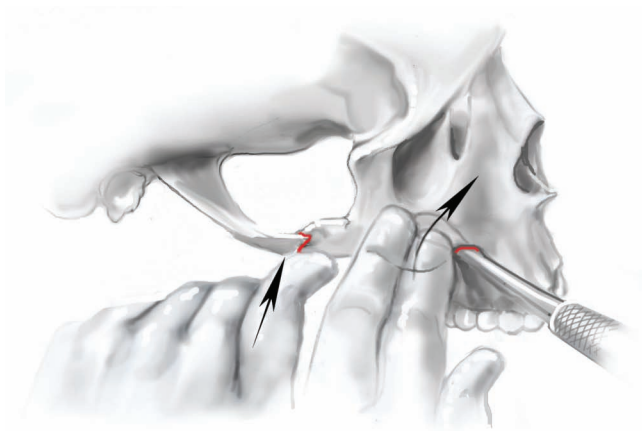


Fig. 6.18

boundary of the *glenoid* (mandibular) *fossa* for receipt of the condyle of the mandible.

After providing a fossa for registration of the condyle of the mandible and after launching its contribution to the zygomatic process, the base of the squama turns inward to interdigitate with the greater wing of the sphenoid. It is joined by the petrous-mastoid complex, as best evidenced from an inferior perspective (**Fig. 6.20**).

The labyrinth is a closed, fluid-filled archipelago of three cavities within the petrous part of the temporal bone: the *semicircular canals*, the *vestibule*, and *cochlea*. The labyrinth is surrounded by extremely dense bone, the *otic capsule*. The semicircular canals are outermost (lateral most)

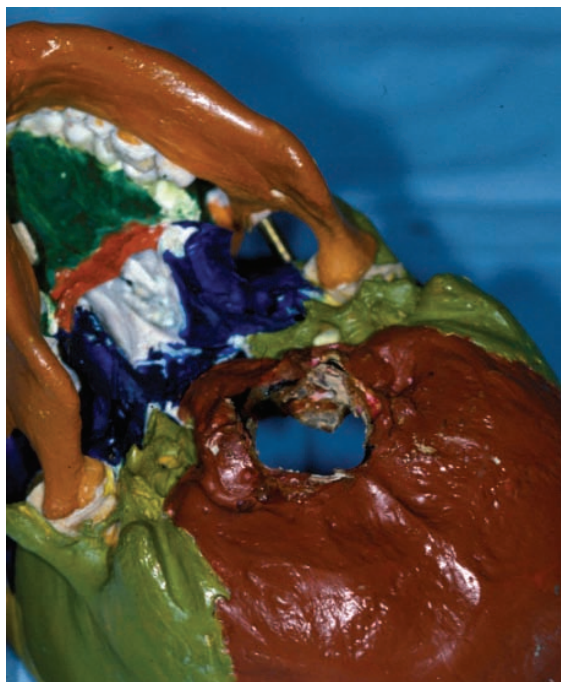


Fig. 6.20

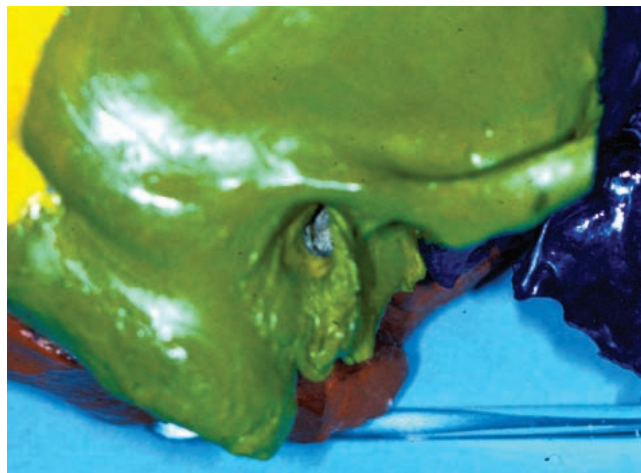


Fig. 6.19

and house the semicircular ducts. The vestibule is a small chamber in which there is the oval window occupied by the base plate of the stapes. The cochlear labyrinth is innermost (medial most) and contains the cochlear duct and a central core, the *modiolus*, about which the cochlear duct is wrapped (**Fig. 6.21**).

Fracture-lines by high-resolution computed tomography (HRCT) either skirt or, in some cases, traverse the dense bone of the otic capsule to end near the join of the temporal bone and the greater wing of the sphenoid, where a cluster of foramina exist (OLS).

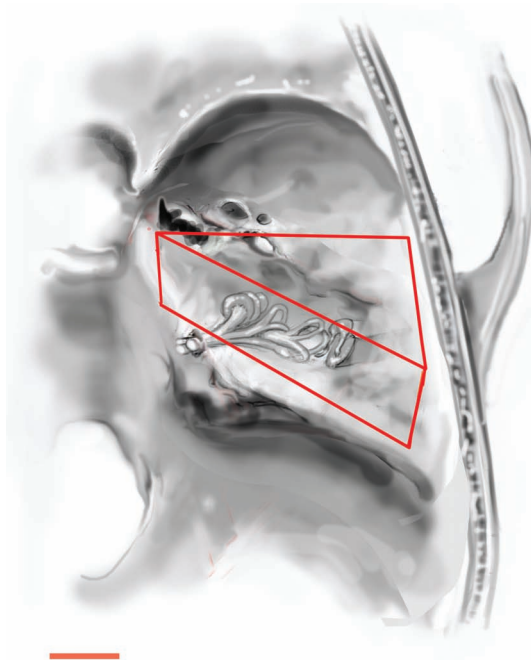


Fig. 6.21

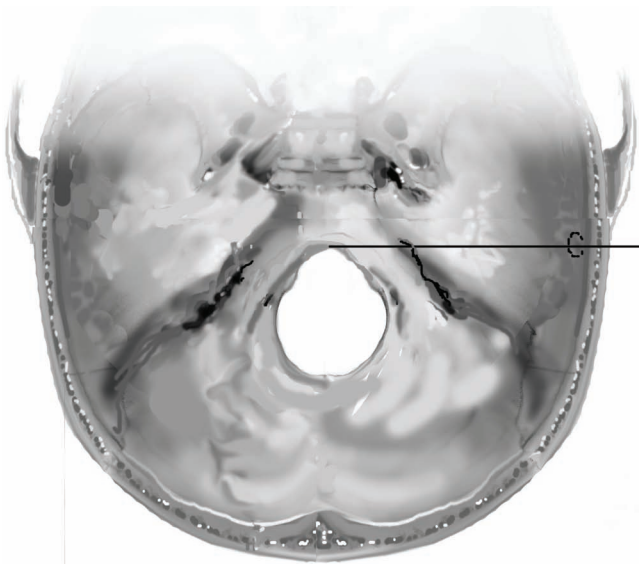


Fig. 6.22

The posterior skull base houses the largest and deepest of the three cranial fossae, the *posterior fossa*, offering lodging for the cerebellum, pons, and medulla oblongata.^{7,30} The occipital bone is its largest contributor, but the petrous and mastoid parts of the temporal bone define its antero-lateral borders (**Fig. 6.22**).

Four foramina are present: the *internal auditory meatus*, *jugular foramen*, *foramen for transit of the hypoglossal nerve*, and the *foramen magnum*. A horizontal line through the anterior margin of the foramen magnum passes through the external auditory meatus but is posterior to the anterior root of the zygoma (zygomatic arch).

■ Part 2. Operative Technique and Exemplary Repair

Injury to the anterior cranial vault may conveniently be perceived as a cascade,¹¹ similar to that suggested by Sturla for nasal injuries and by Pollock for palatal fractures. This concept encourages thorough clinical examination and radiographic assessment beyond the zone of apparent trauma because of high incidence of collateral injury (**Fig. 6.23**).

Preoperative Assessment and Indications for Repair

Clinical Presentation

Widespread injury is often present when load forces of sufficient magnitude reach the cranial base and fractures of the anterior, middle, and/or posterior cranial vault

occur.^{1,3,19,21–23,31–46} The clinical findings are thus often diverse. Central nervous system injury may be present but relatively occult (i.e., cerebral contusion), such that it is apparent only to discerning examination. Lacerations over the frontal boss, temporal fossa, or occipital scalp are more obvious, but in the presence of fracture may violate the dura, creating a conduit that allows CSF leak. *By definition, an intracranial injury should be suspected in this setting until proven otherwise.*

The passage of blood through intracranial vessels may cause secondary, pulsatile movement of the globe of the eye when fractures of the medial orbital roof (lateral frontal sinus floor) are present. Also, the temporal bone is closely aligned with vascular structures, such as the venous sinuses and jugular bulb. It is thus no surprise that patients with temporal fractures may present with hemotympanum, or venous blood in the external auditory canal.

Consultation with multiple specialties is expected in these patients with diverse injury. Repetitive study of radiographs and serial clinical examination of the patient are advised⁴⁶ to uncover occult pathology, such as cerebrospinal leak (rhinorrhea and/or otorrhea), cranial nerve dysfunction, epidural hematoma, or injury to brachial plexus or cervical spine (see Chapters 2 and 9).

The modified Glasgow Coma Scale (GCS) first reported by Teasdale and Jennett⁴⁷ (15 the best prognosis, and 3 the worst) and the Brain Injury Index described by Jennett and Bond⁴⁸ (Grade I, loss of consciousness, to Grade IV, brain death) are useful measures that quantify the severity of head injury and the level of consciousness. Although the statistical relationship between the intracranial injury and a specific craniofacial fracture is imprecise,⁴⁹ most patients with severe head injuries (a score of less than 8 GCS) or major skull fractures (open, depressed, basilar, or compound) usually trigger early neurosurgical intervention.^{50,51}

Neurosurgical intervention in patients with *combined* injuries of the cranium and face is undertaken on average in one of three cases. In the two of three cases, no deviation from routine management of facial fractures is required, despite the additional presence of cranial fractures, because their cranial injuries are solely observed for evidence of increased intracranial pressure.^{49,52,53}

Medical management is directed toward the resolution of cerebral edema and restoration of cerebral microperfusion⁵⁰ with high, so-called neurosurgical doses of steroid. An infusion of 1 to 2 g of methylprednisolone every 6 hours is not uncommon for a brief period of time. Maurice-Williams²⁷ has recently urged awareness of temporal lobe contusion (and regional edema) associated with craniofacial injury, such as might occur in the presence of fracture(s) of the greater wing of the sphenoid and posterior displacement (buckling) of the orbital plate of the zygoma.

Cascade of Injury to the Anterior and Middle Cranial Vault and Cranial Base:**SOFT-TISSUE INJURY, INCLUDING FOREHEAD AND SCALPING LACERATIONS****FRONTAL SINUS TABLE (ANTERIOR AND POSTERIOR) FRACTURES;
FRONTAL LOBE CONTUSION****COLLAPSE AND COMMUNION OF FRONTAL SINUS FLOOR****MEDIAL****FRACTURE OUTFLOW TRACT****NASAL-NASOSEPTAL, NASOMAXILLARY, ORBITOETHMOID INVOLVEMENT****LATERAL****FRACTURE MEDIAL ORBITAL ROOF****COMMUNION OF CRIBRIFORM PLATE AND FOVEA ETHMOIDALIS
WITH SHEARING OF OLFACTORY NERVES****BASILAR FRACTURES OF THE SPHENOID SINUS
AND LATERAL ASPECT OF GREATER WINGS OF SPHENOID****CONTUSION OF TEMPORAL LOBES****TRANSVERSE (AND/OR LONGITUDINAL) FRACTURES OF PETROUS
PYRAMID; FRACTURES AT THE PTERION, WITH EPIDURAL HEMATOMA**

Fig. 6.23

Radiographic Assessment

HRCT has been available for some 30 years, and isolated fractures of the anterior cranial vault and combined injuries of the cranium and face have been a focus of interest for the duration.^{25,35,37,54} These radiographic studies now offer the radiologist, neurosurgeon, and reconstructive trauma surgeon a clear declaration and record of the extent of combined injury.

Routine radiography and screening computed tomography (used in emergency departments to document expanding subdural or epidural hematoma) do *not* provide

sufficient detail of fractures of this obscure region. Computed tomography sent with patients from regional centers often cannot be used in the presence of severe injury.

HRCT with 1.5- to 2.0-mm cuts offers greater detail of the injury and favor appropriate care and defined surgical intervention.

Frontal Sinus Fractures

Fractures of the frontal sinus may be isolated to either the anterior table or the posterior table or involve both tables.

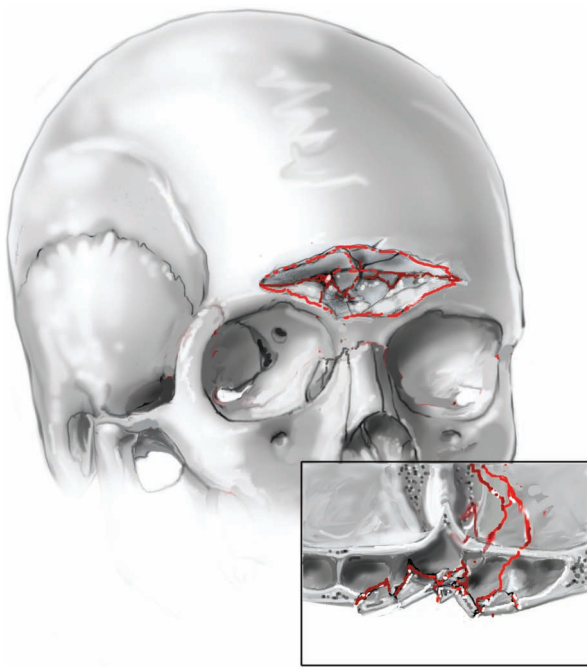


Fig. 6.24

The injury similarly may traverse the floor of the frontal sinus medially, laterally, or both. In the extreme, the frontal sinus fracture is part of a fault extending to the cribriform plate and the skull base (**Fig. 6.24**).

Fractures of the *frontal sinus* are arbitrarily and conveniently divided into four components,¹¹ based on radiographic assessment by HRCT:

1. The anterior table
2. Medial sinus floor, FSOFT, and nasoethmoid complex (anterior and middle ethmoid cells)
3. Lateral sinus floor and anteromedial orbital roof
4. The posterior table and dura (particularly in the area of the crista galli)

Parasagittal views of *each of these four areas* today allows detailed planning for operative intervention. Plans may be formulated in advance, and outcomes are improved¹¹ (**Fig. 6.25**).

Fractures of the anterior table are dependent on the pneumatization of the frontal sinus. Lacerations over the frontal boss are common and may extend upward as a scalping avulsion or may descend to involve the nasal and nasomaxillary regions.

Displaced fractures of the posterior table of the frontal sinus imply rents in the dura and suggest the need for neurosurgical consultation and surgical intervention. Fractures of the posterior table on occasion occur without fractures of the frontal sinus floor or anterior table; in our experience, this occurs with trauma to the back of the head (occipital impact, leading to occipital-frontobasilar

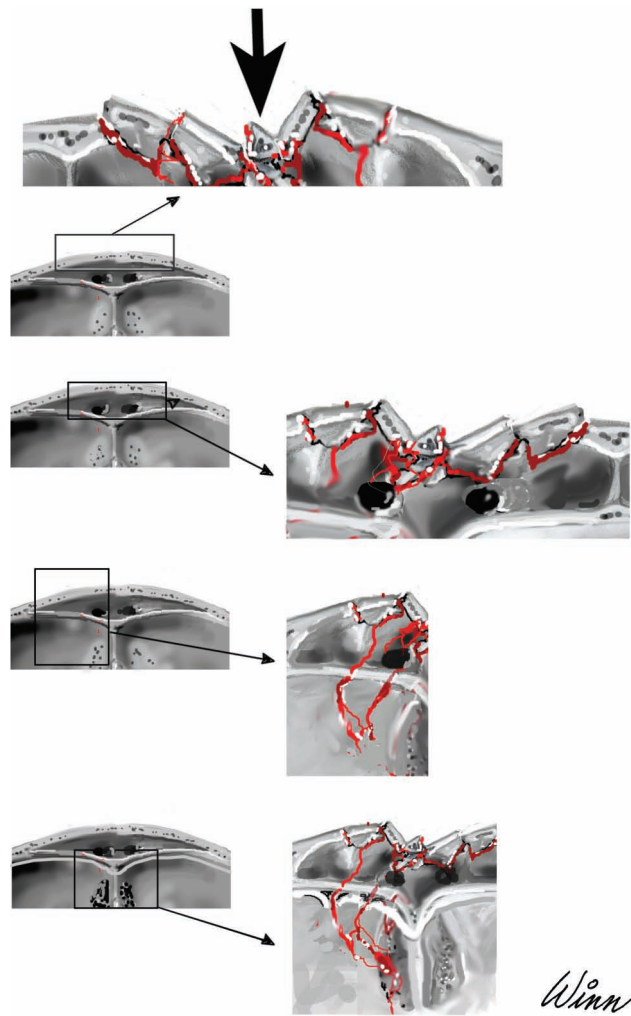


Fig. 6.25

fracture). The incidence of posterior table or anterior-and-posterior table fractures has progressively increased since the mandated use of seatbelts and the ensuing increased rates of survival (**Fig. 6.26**).

Basilar Fractures

Isolated fractures of the ethmoid and sphenoid roof are obscure and best referred to simply as *basilar*. In their

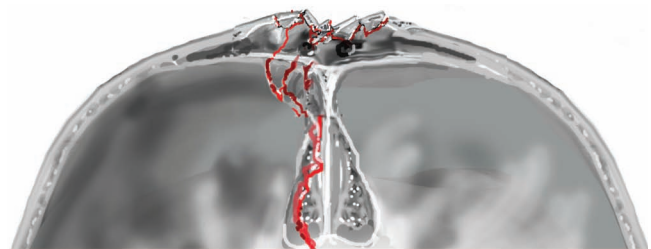


Fig. 6.26

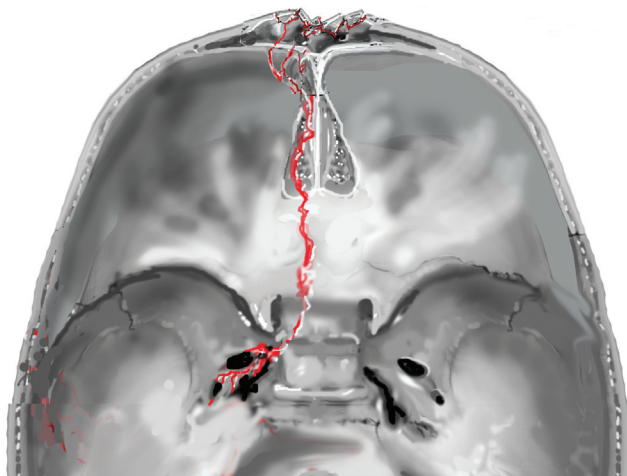


Fig. 6.27

presence, “coned down” views of the optic strut and optic canal (see Chapter 8) and the wings of the sphenoid are taken. Most frontobasilar fractures deviate laterally when reaching the roof of the sphenoid sinus, to end at the *foramen ovale*, *foramen lacerum*, *foramen spinosum* (OLS), or *carotid canal*.

Frontobasilar Fractures

Fractures of the floor of the frontal sinus and posterior table may extend through the base of the crista galli, cribriform plate (ethmoid), and roof of the sphenoid sinus. In this instance, the fracture is said to be *frontobasilar*.^{21,37,54} Like isolated basilar fractures, the frontobasilar fracture ends among the cluster of foramina (OLS) in the posterolateral sphenoid (**Fig. 6.27**).

Temporobasilar Bone Fractures

Fractures of the *temporal* bone are seldom isolated. More often, a fracture sufficient to extend through the dense bone of the petrous pyramid also involves paratemporal bone. In a large majority, the fault also reaches the nearby cluster of foramina (OLS) in the greater wing of the sphenoid. Thus, it follows in many cases, temporal bone fractures are in fact *temporobasilar*. The term is more inclusive and more descriptive of the extent of injury, and we have long encouraged its use when appropriate.

Temporobasilar fractures are parallel, transverse, or oblique to the long axis of the petrous pyramid.^{55–72} The incidence of these categories varies greatly between surviving patients and postmortem cohorts,^{58–62,64,66,71} creating controversy.

Eighty percent of *temporobasilar* fractures are said to be longitudinal because they parallel the architecture of

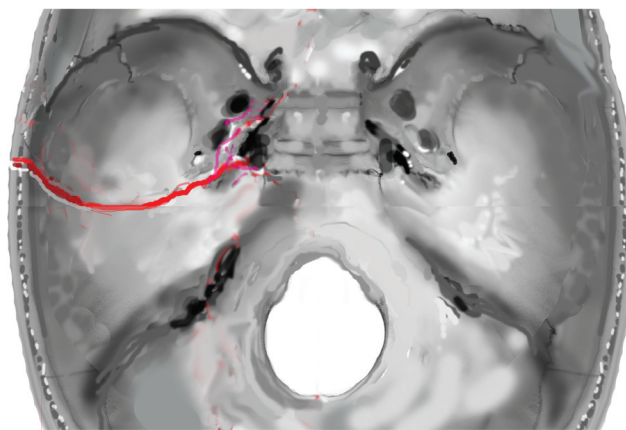


Fig. 6.28

the pyramid. They usually follow a blow to the *side* of the head. The fracture begins in the bony ear canal (at the posterior root of the zygomatic process), traverses the tympanic membrane, crosses the notably thin attic (roof) and tegmen tympani of the middle ear cavity, skirts the roof of the glenoid fossa and the labyrinth (otic capsule), and runs near the margin of the carotid canal, ending in the cluster of foramina (OLS) nearby (**Fig. 6.28**).

Some one in five patients with longitudinal temporobasilar fractures suffer facial nerve paralysis and, when present, it tends to be *incomplete*.^{56,59,60} Most facial nerve injury associated with longitudinal fracture occurs in the area of the *geniculate ganglion*. Some authors suggest that traction on the facial nerve by the greater petrosal nerve, in the area of the ganglion, plays a role in the etiology of this injury.⁶⁹

When the longitudinal fault crosses the middle ear cavity, there is usually tympanic disruption and perhaps ossicular derangement.^{60,61,70,71} Hough suggests a specific incidence, in *decreasing* order, when such is the case: incudostapedial separation >>> incus dislocation (“incudo-toss”) >> fracture of the stapedial arch > fracture of the handle of the malleus.⁶¹

Upon disruption of the ossicular chain, the “molar tooth” sign, created by the outline of the malleus and the incus in the lateral HRCT projection, is obscured. The “crown of the tooth” is formed by the head of the malleus and the body of the incus, the “anterior root” by the handle of the malleus, and the “posterior root” by the long process of the incus,⁷³ and these normal features are disrupted after trauma. Middle ear exploration/reconstruction may be required to reconstitute the displaced ossicular chain (**Fig. 6.29**).

Twenty percent of temporobasilar fractures are transverse or mixed fractures of the temporal bone⁶⁸ and often are part of occipitobasilar fractures.

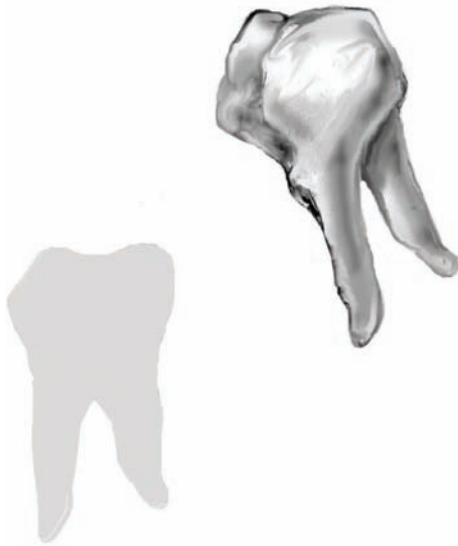


Fig. 6.29

Occipitobasilar Fractures

Occipitobasilar fractures are less common than frontobasilar or temporobasilar injury and often follow a blow to the back of the skull. Posteroanterior buckling has been speculated as the probable cause of injury.³⁴

The fault begins in the occipital bone and cuts across the jugular foramen before it traverses the petrous pyramid (perpendicular to its long axis). A swath of damage occurs, as the transverse fracture skirts the middle ear to cut across the internal auditory meatus and labyrinth (inner ear), to end in the *foramen ovale* or other foramina nearby (Fig. 6.30).

Patients with occipitobasilar and temporal fracture have a total neurosensory hearing loss, and the trauma is

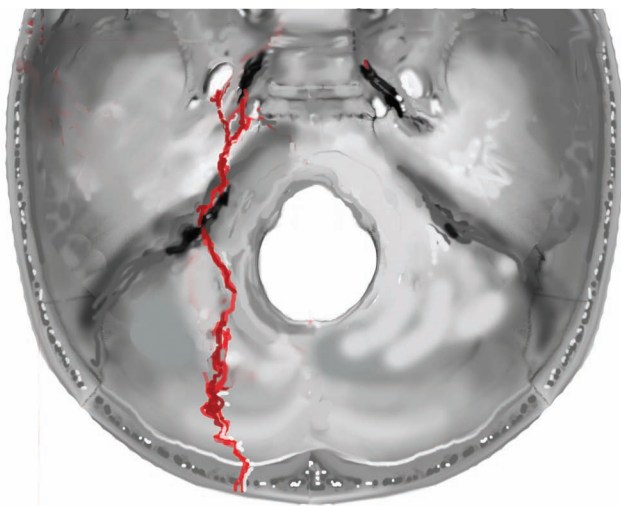


Fig. 6.30

often such that the stapes is totally expelled from the oval window.

Involvement of the otic capsule in these transverse fractures of the temporal bone is a strong predictor of clinical outcome.^{38,70} Thus, radiographic reports of occipitobasilar fracture in general and transverse temporal bone fracture in particular are best amended to clearly record the status of the labyrinth. In terms of temporal fracture classification and the ability to predict future hearing loss, fractures involving the outer surface of the temporal bone (squama) are ignored, as emphasized by Ghorayeb and Yeakley.⁷²

About half of the patients with transverse fractures suffer *total* facial paralysis because of facial nerve injury in the “labyrinthine segment” of the fallopian canal. The surgeon is aware of concomitant abducens nerve paralysis, trigeminal nerve paralysis, and sigmoid sinus thrombosis after transverse injury⁷⁴ (Fig. 6.31).

Pancraniobasilar Fracture

Although usually confined to a nonsurviving cohort, frontobasilar, temporobasilar, and occipitobasilar fractures may combine as a common fracture. The fault in these extreme cases of injury extends from the frontal boss to either the temporal cranial vault or the occipital vault, or both.

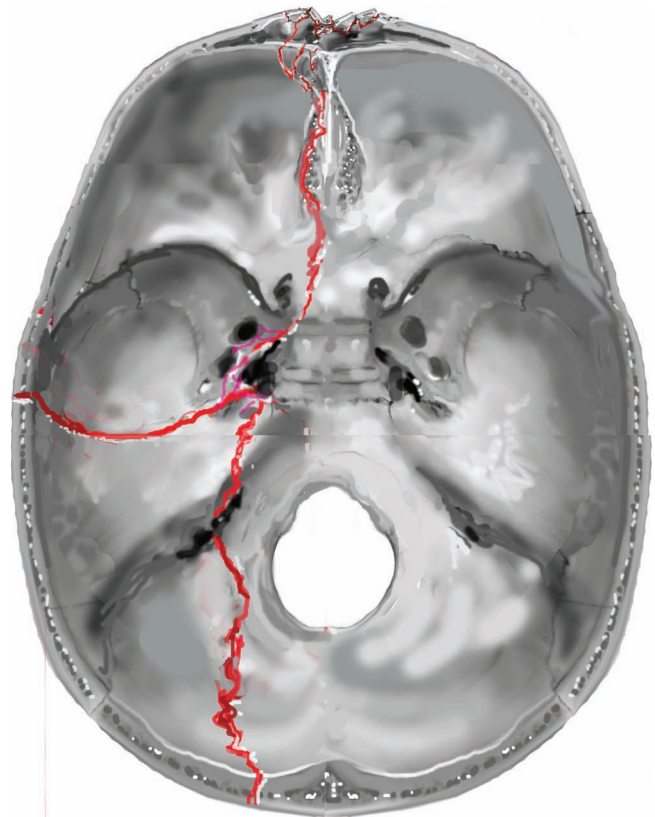


Fig. 6.31

Operative Repair

The controversy regarding management of fractures of the frontal bone began in 1965, and there have been a series of landmark articles since that time.^{11,40,75–108} Fractures of the sphenoid, temporal, and occipital bones less often trigger surgical intervention in survivors, unless the optic or facial nerves are involved; even then, temporal bone surgery and facial nerve repair are usually achieved in a deferred fashion as a separate procedure after electroneuronography and other nerve testing. Preoperative consultation with neurosurgical and otolaryngologic colleagues is common (**Fig. 6.32**).

Incisions and Prealignment

Fractures of the frontal boss, frontal sinus, orbital roof, and medial and lateral upper orbital frame are readily exposed through the coronal incision. Fractures of the optic canal are approached by an extracranial, transethmoidal approach (see Chapter 8) and displacement of the greater wing of sphenoid is approached through the coronal incision and elevation of the temporalis muscle. Repair of the facial nerve in the fallopian canal is pursued after a postauricular incision, which is common to mastoidectomy;

the auricle is folded forward, and cutting burrs are used to uncover (decompress) the injured nerve.

The coronal incision was first described in the literature in the late 1920s. The original incision, extending from auricle to auricle, has been modified to favor an acceptable scar and minimize the risk of alopecia. Thus, the incision in the temporoparietal region is beveled toward the occiput. Medial to the temporal line, the incision is perpendicular to the surface of the scalp or slightly beveled forward in the direction of hair follicles. Raney clips (to thwart hemorrhage) are applied over gauze rather than directly on the scalp. The incision may be designed in a serpentine manner to favor proper wound closure and to obscure scar (**Fig. 6.33**).

The incision is carried through the layers of the scalp to reach the periosteum. The dissection is then carried forward in the loose areolar plane between the periosteum and the galea to favor advancement of the scalp. Some 2.5 cm above the superior orbital rim, the fifth layer (periosteum) is incised, and the dissection proceeds along the outer cortex of the frontal boss with a Molt #9 elevator. The supraorbital nerves, as they exit the supraorbital notch, are thus protected. The incision may descend below the level of the root of the helix when greater exposure is required.

Algorithm of Repair:

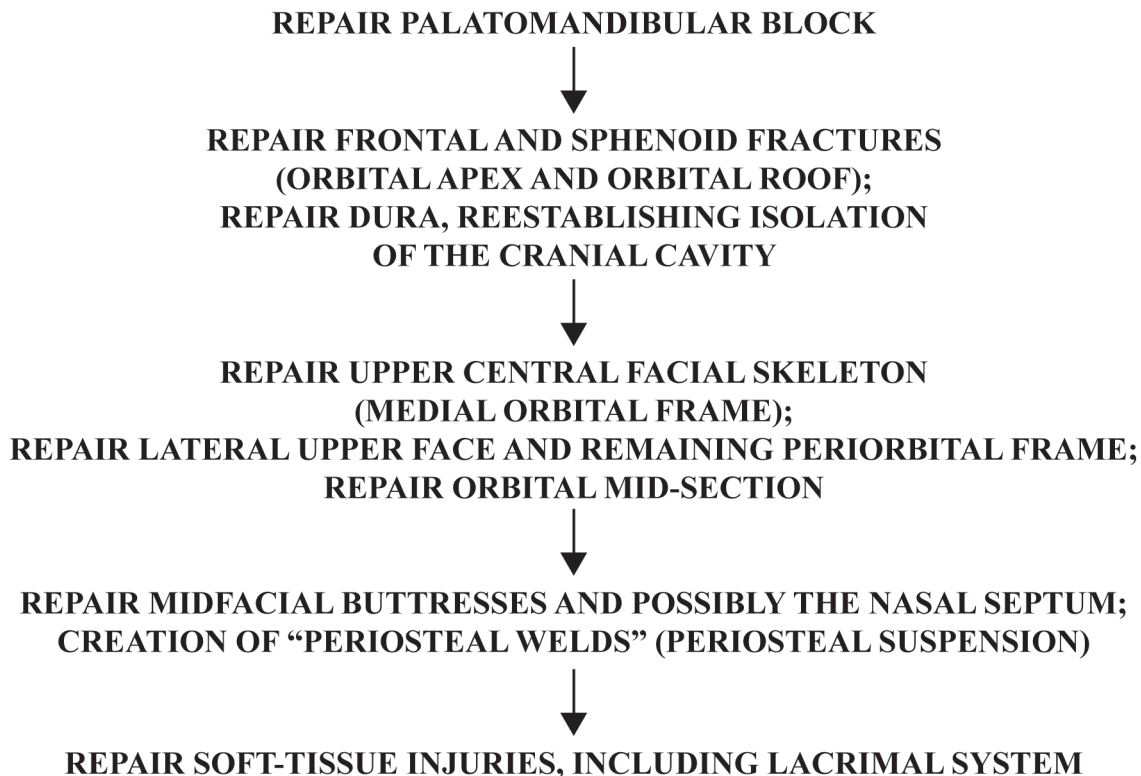


Fig. 6.32

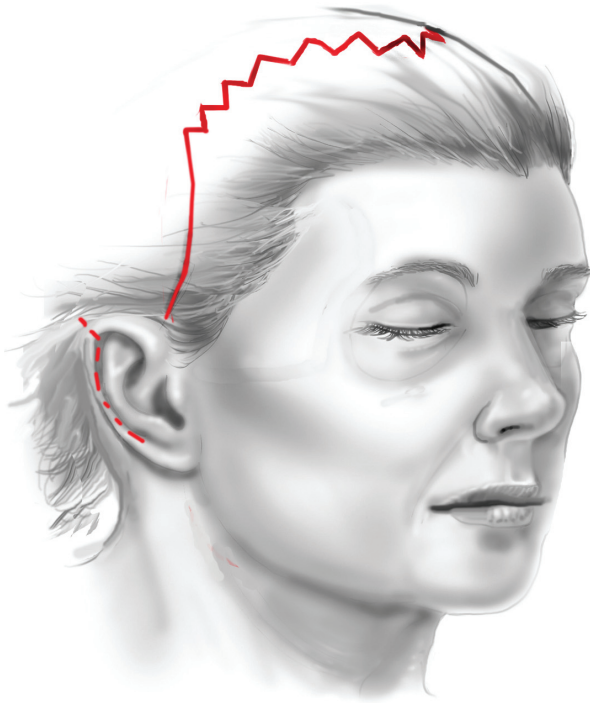


Fig. 6.33

Fragments of the anterior table may be removed to allow inspection of the posterior table, sinus floor, and outflow tract. The fragments are secured to mesh or plates with screws, then reinserted as an assembly (see Chapter 2) to reestablish the continuity of the frontal boss.

Outflow Tract Obliteration and Sinus Cranialization

Management of fractures of the *anterior* table took years to resolve, and management of fractures of the *posterior table*, *floor*, and *outflow tract* in particular created controversy until the recent decade. The basis of surgery was greatly clarified with the development of HRCT, an emphasis on the seminal role of the FSOFT,^{82,89,96} and frontal sinus mucosa (“birth lining”).¹⁷

It was in the use of adjuncts that competing points of view arose. Some clinicians favored use of abdominal fat as an avascular interface between the anterior table and cranial cavity,^{75,76,84,107} whereas others proposed letting the cranial cavity expand into the former sinus space (*cranialization*).^{11,22,24,25,103} In both “camps,” obliteration of the outflow tract was favored.

The debate seesawed back and forth^{75–107} until 2008 and 2009, when reports by Rodriquez and Pollock and their respective coauthors brought the controversy to a relative close.^{11,108} These two large series over some 25 years obtained excellent outcomes after 1) *meticulous mucosal*

and posterior table *débridement*, 2) *obliteration* of the infundibulum of the FSOFT with orts of bone⁹⁴ and Gelfoam® (Pfizer Inc., New York, NY), and 3) *cranialization of the sinus* (Fig. 6.34).

Bone orts (chips of outer skull cortex) and small pieces of Gelfoam® are packed into the infundibulum and ostium of the outflow tract. Posterior table fragments are *not* used for fear that occult mucosa would bias the obliteration and risk mucopyocele. Fat transplant has become recognized as extracting little cost but affording little benefit by statistical and clinical analysis, and early dissuasions against its use have proven correct.^{92,109}

A pericranial (periosteal) flap, used as a biologic barrier or veil, appears to have benefit in selected cases, as advised by Wolfe,¹¹⁰ Argenta and colleagues,¹¹¹ Thaller and Donald,⁹³ and Yavuzer and colleagues,¹¹² notably in the presence of extreme frontal/frontobasilar injury. The pedicled pericranial flap reaches the anterior orbitoethmoid roof. Prospective study and multicenter meta-analysis would help define more specific indications for its use, when compared with other biologic barriers, such as fascia lata.

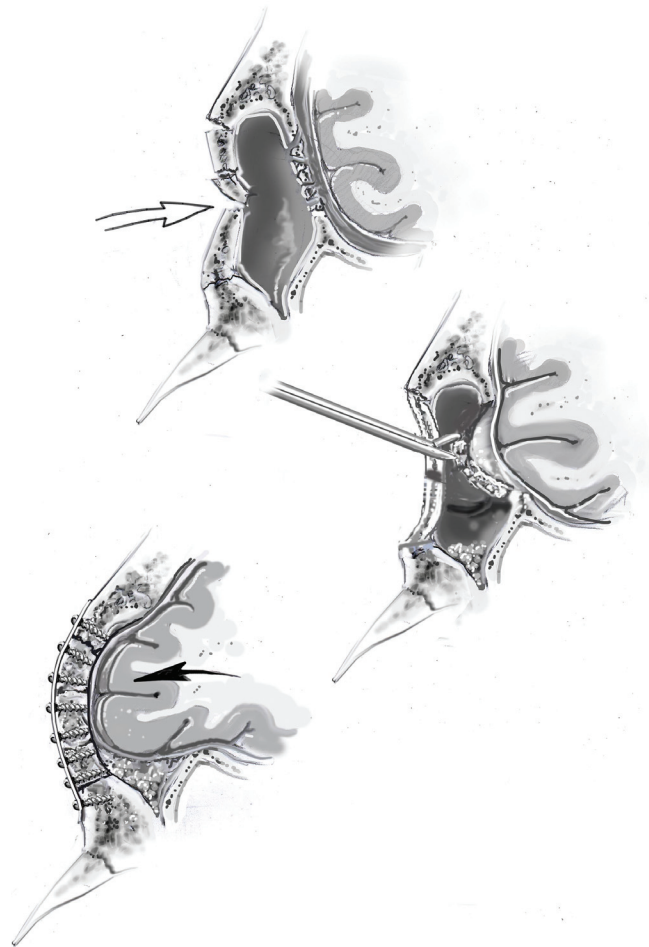


Fig. 6.34

Approach to Collateral Damage

Several early studies, including that by Kaufman and colleagues in 1984, suggest a *higher rate of complication* in patients with coexisting neurological injury and craniofacial fracture,⁵² and in a general way, complications and risk appear to be proportional to complexity, notably after pancraniobasilar injury. Studies to date, however, have not been able to specify the relationships between brain injury and specific craniofacial, even “routine” facial, injury.

The study by Haug, Van Sickels, and Jenkins in 1994,⁴⁹ for example, identifies no reliable correlation between *individual* cranial (frontal, sphenoid, temporal) fracture, *individual* facial injury, and the development of *specific* complications. Thus, so far, correlates that portend greater collateral risk have yet to be identified and may not be clinically apparent until meta-analysis of data from several centers and/or further controlled laboratory study.

Temporal Lobe Injury and Amaurosis

The middle fossa is deepened to house the temporal lobe of the brain, and the cortex of the anterior pole of the temporal lobe lies immediately deep to the greater wing of the sphenoid. Thus, when fractures of the greater wing of the sphenoid or temporal bone are present, damage to the contents of the deep lateral orbit (perhaps the optic canal, optic strut, or superior orbital fissure) (see Chapter 8) or contusion of the anterior pole of the temporal lobe of the brain is suspected. The occult temporal lobe injury is evident only by magnetic resonance imaging and, about half the time, the contusion is located immediately adjacent to the site of sphenotemporal fracture and the involved greater wing of the sphenoid.^{27,113,114}

Jend and Jend-Rossmann describe a double fracture of the lateral wall of the orbit involving the greater wing of the sphenoid and the anterior squama of the temporal bone, thus a T-shaped “sphenotemporal buttress fracture.”¹¹⁴ All surviving patients in their small series suffered temporal lobe injury *and* amaurosis (blindness without radiographic evidence of compromise of the optic canal).

Cerebrospinal Fluid Leak

CSF leak occurs in 1 to 4% of temporal bone fractures, confirmed by a positive halo test and β -2 transferin or β -trace protein in the drainage. The drainage abates spontaneously in some two of three cases within 7 days. In the remaining third, a vast majority respond to intermittent or extended use of a closed lumbar drainage system. The locus of the leak is often apparent by HRCT and dye injection.

In cases of *otorrhea*, the site of CSF leak is frequently discovered as the longitudinal temporobasilar fault crosses the tegmen and attic (roof) of the middle ear cavity. In the case of frontobasilar fracture and *rhinorrhea*, the rent in the dura is usually found near the posterior table of the frontal sinus or near the crista galli. Both rhinorrhea *and* otorrhea may be present in the patient with frontotemporobasilar fracture.

Dural tears are sutured, and the repair is reinforced with Gelfoam pledgets, fascia lata, or superficial temporal fascia adapted with fibrin glue. Surgery is chosen to seal the site(s) of leakage in the few that fail to abate spontaneously or respond to closed lumbar drainage. Antibiotics are avoided for fear of creating resistant organisms in the absence of compelling evidence of their benefit.^{115–119}

Meningitis

Long-term risk of meningitis in those patients with isolated CSF leak has been increasingly delineated. The subset of patients with documented acute otorrhea *and* rhinorrhea has not been statistically assessed, but it would seem logical that a higher incidence of meningitis follows elongated vault-to-vault or vault-to-cranial base fracture.

Cavernous Sinus Thrombosis

In rare instances, infection may enter the skull base by traveling in a retrograde manner through the valveless facial and ophthalmic veins to reach the anterior portion of the cavernous sinus. *Cavernous sinus thrombosis* and other sequelae may result.

Frontomucopycele

Patients are vulnerable to *frontomucopycele* within some 20 years of repair of frontal sinus fracture. Serial follow-up accompanied by HRCT may reveal bone-erosive pyocele when serial follow-up is possible.

Narrowing of the nasofrontal recess may occur after isolated *nasomaxillary* injury, with early, apparent sparing of the frontal sinus. The narrowed recess may be occult or deemed insignificant until the accelerated, some would say “paradoxical,” development of a frontal mucopycele or fulminant frontal sinusitis.

Removal of the implicit obstruction and preservation of the sinus mucosa may now be achieved in a high percentage of cases when the mucopycele is discovered using sinus endoscopy techniques. A 70-degree endoscope affords good visualization of the frontal recess and frontal sinus ostium. Removal of the middle ethmoid cells (so-called anterior ethmoidectomy) may be indicated.

Exemplary Repair

Case 7. Frontal Sinus and Supraorbital Rim Fractures

This patient was struck by a softball just off the midline and sustained fractures of the anterior table of the frontal sinus. Upward gaze was restricted by a downwardly displaced fragment of the right orbital rim (Fig. 6.35A–D).

Blood clot and debris were removed, and it was confirmed that the posterior table was intact. A “bone assembly” was created using a large bone fragment and

an adaptation plate to reestablish the anterior table (Fig. 6.35E–H).

A small split cranial bone graft replaced small parts, and the graft was prealigned with wire before application of plates and screws (Fig. 6.35I,J).

The fractures of the superior orbital rim were elevated and stabilized with plates and screws, including a Y-shaped plate that was bent to secure a graft within the roof of the orbit. Mesh is today available as an alternate to multiple straight plates, but, either way, a large number of appliances are required to repair injuries over a broad area (Fig. 6.35K–M).

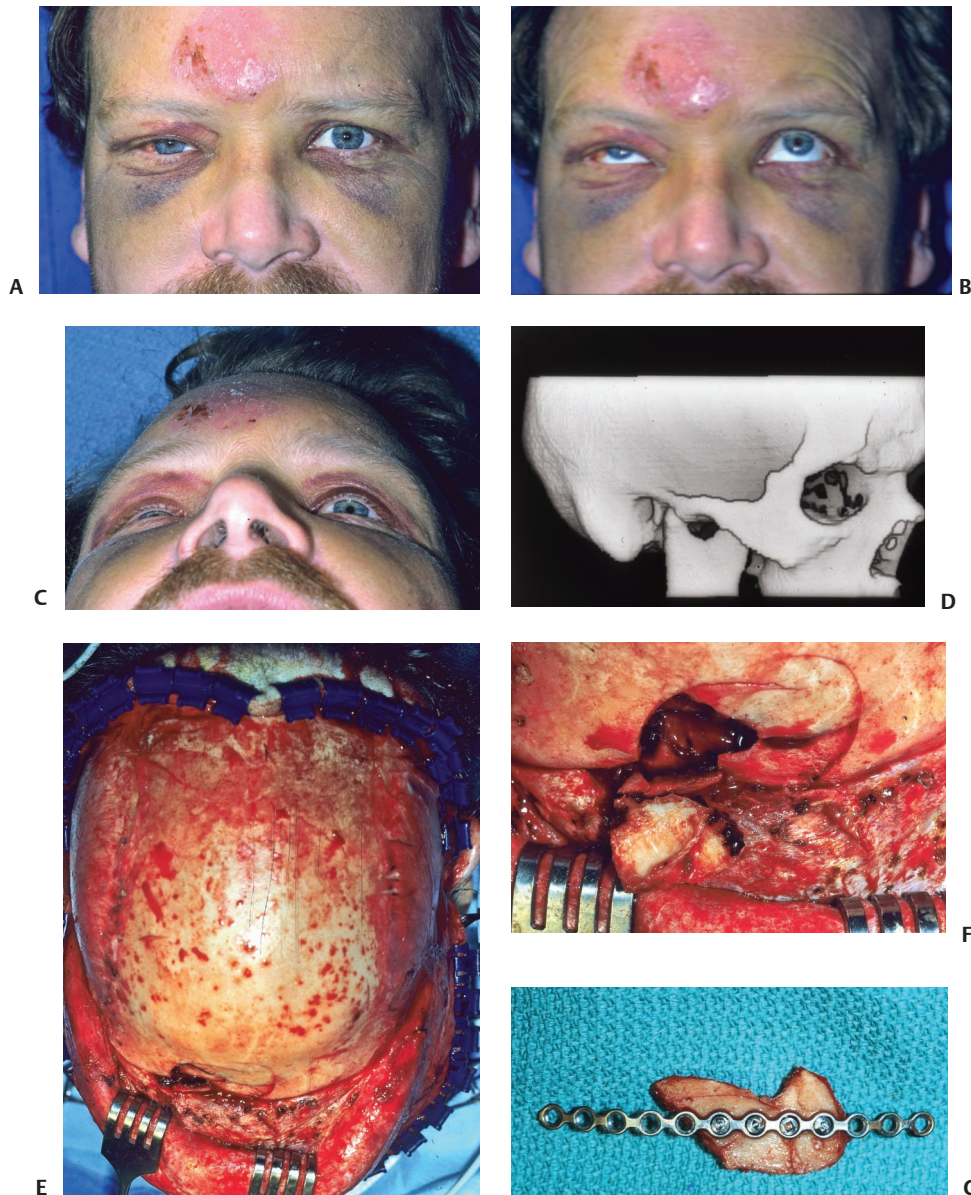


Fig. 6.35 (A–G) (Continued)



Fig. 6.35 (Continued) (H-M)

Case 8. Frontal Sinus (Anterior and Posterior Table) and Orbital Roof Fractures, With Cranialization

This teenager presented with an L-shaped laceration of the forehead and transient obtundation (concussion) (Fig. 6.36A-D).

A coronal incision favored full exposure and exploration, then débridement of small fragments and debris (Fig. 6.36E-G).

Disruption of the posterior table and CSF leak were confirmed at surgery. The posterior table and its fragments were removed, the mucosa was meticulously removed

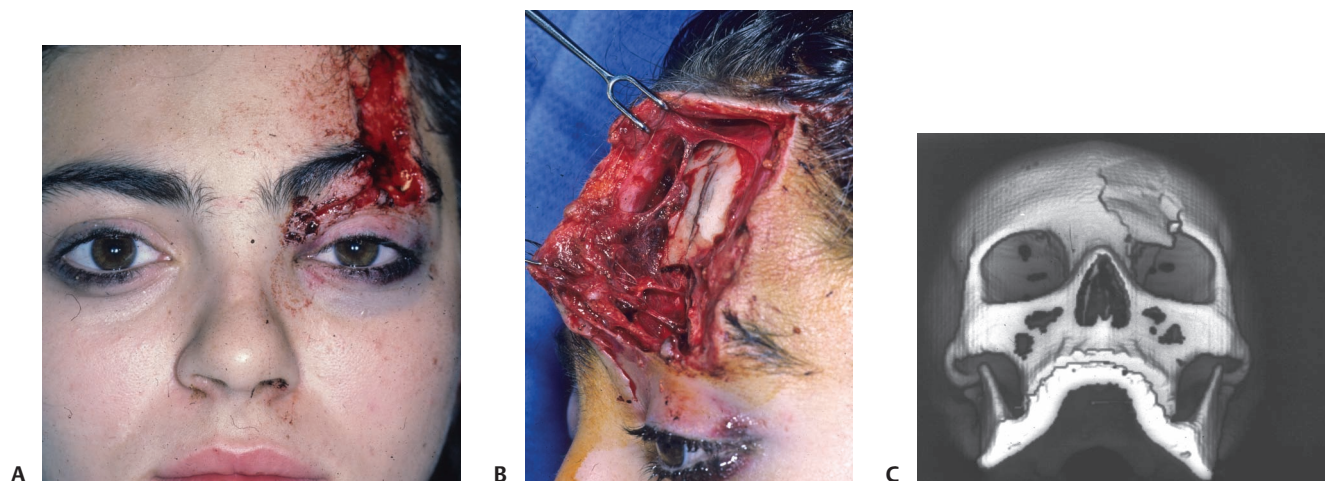


Fig. 6.36 (A-C) (Continued)

with cutting burrs, and the FSOFT was obliterated with Gelfoam and bits of bone, completing the cranialization (Fig. 6.36H).

The superior orbital rim was reconstructed with an assembly of bone and a long plate.

Two split cranial bone grafts were harvested from the posterior temporoparietal skull, above the temporal line. The margins of the graft were trimmed with cutting burrs to match the shape of the defect in the anterior table of the

frontal sinus. The fragments and the graft were assembled, using appliances, as depicted (Fig. 6.36I-L).

Cutting burrs were used to trim and bevel the rim of the graft to match the defect in the medial roof of the orbit. When stained with methylene blue (for photographic purposes), the graft resembles a "top hat." The natural contour of the temporoparietal skull nicely matches the contour of the frontal boss and the orbital roof (Fig. 6.36M,N).

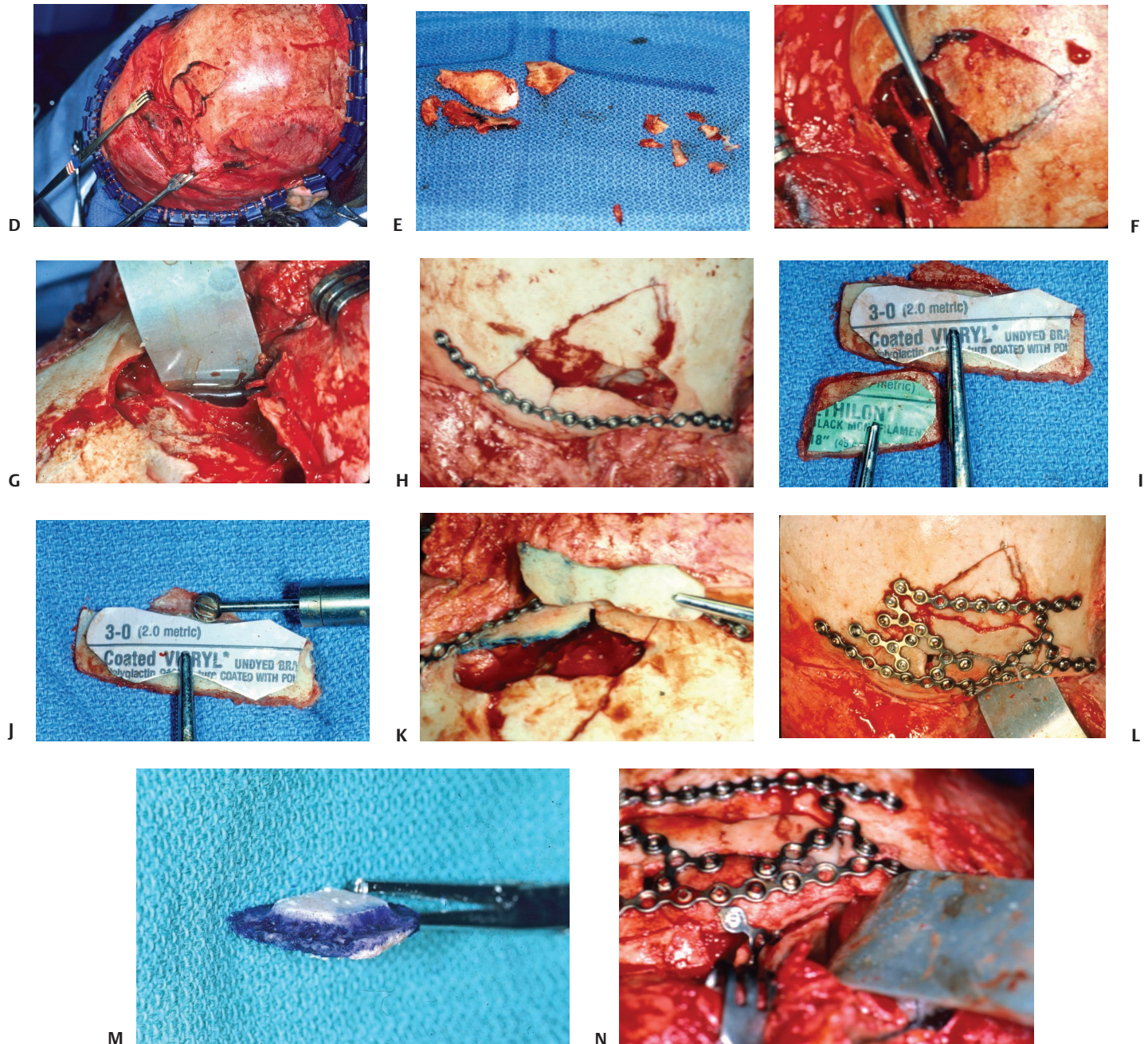


Fig. 6.36 (D-N) (Continued)



Fig. 6.36 (Continued) (O-Q)

The patient is pictured some 3 years following surgery, with minimal forehead scar and with normal forehead and brow function (Fig. 6.36O-Q).

Case 9. Frontal Sinus, Medial Roof, and Medial Floor Fractures, With Cranialization

Polyethylene (the middle layer of many automobile windshields) was imbedded in the scalping laceration of this patient during a high-speed vehicular accident (Fig. 6.37A-D).

A dural tear in the area of crista galli was repaired with suture.

Burr holes with a Midas Rex® drill (Medtronic Inc., Jacksonville, FL) allowed the removal of the frontal boss. Removal of foreign body and the disrupted posterior table, repair of the dura, meticulous removal of the mucosa of the anterior table with cutting burrs, and obliteration of the FSOFT with Gelfoam and bone chips followed, achieving so-called cranialization of the frontal sinus. Note the assembly created for reconstruction of the anterior table, using bone and appliances (Fig. 6.37E-H).

Contoured split cranial bone was used to repair defects of the medial orbital roof and the medial orbital wall. The graft, beveled with cutting burrs and stained with meth-

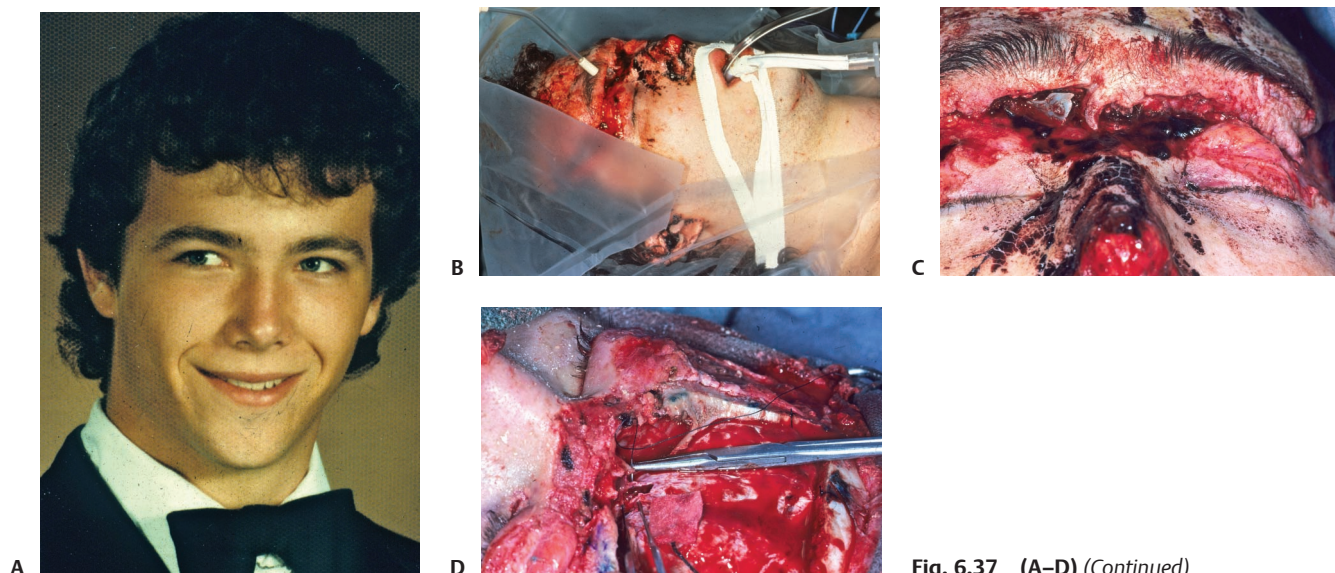


Fig. 6.37 (A-D) (Continued)

ylene blue for photographic purposes, snapped into place and was not secured at the medial orbital rim. A meshed full-thickness skin graft was applied to an avulsed area of the right upper eyelid (**Fig. 6.37I**).

The graft was “pie-crusting” with a scalpel to reduce tension on the eye lid margin (**Fig. 6.37J,K**).

The patient is depicted approximately 4 years after surgery (**Fig. 6.37L,M**).

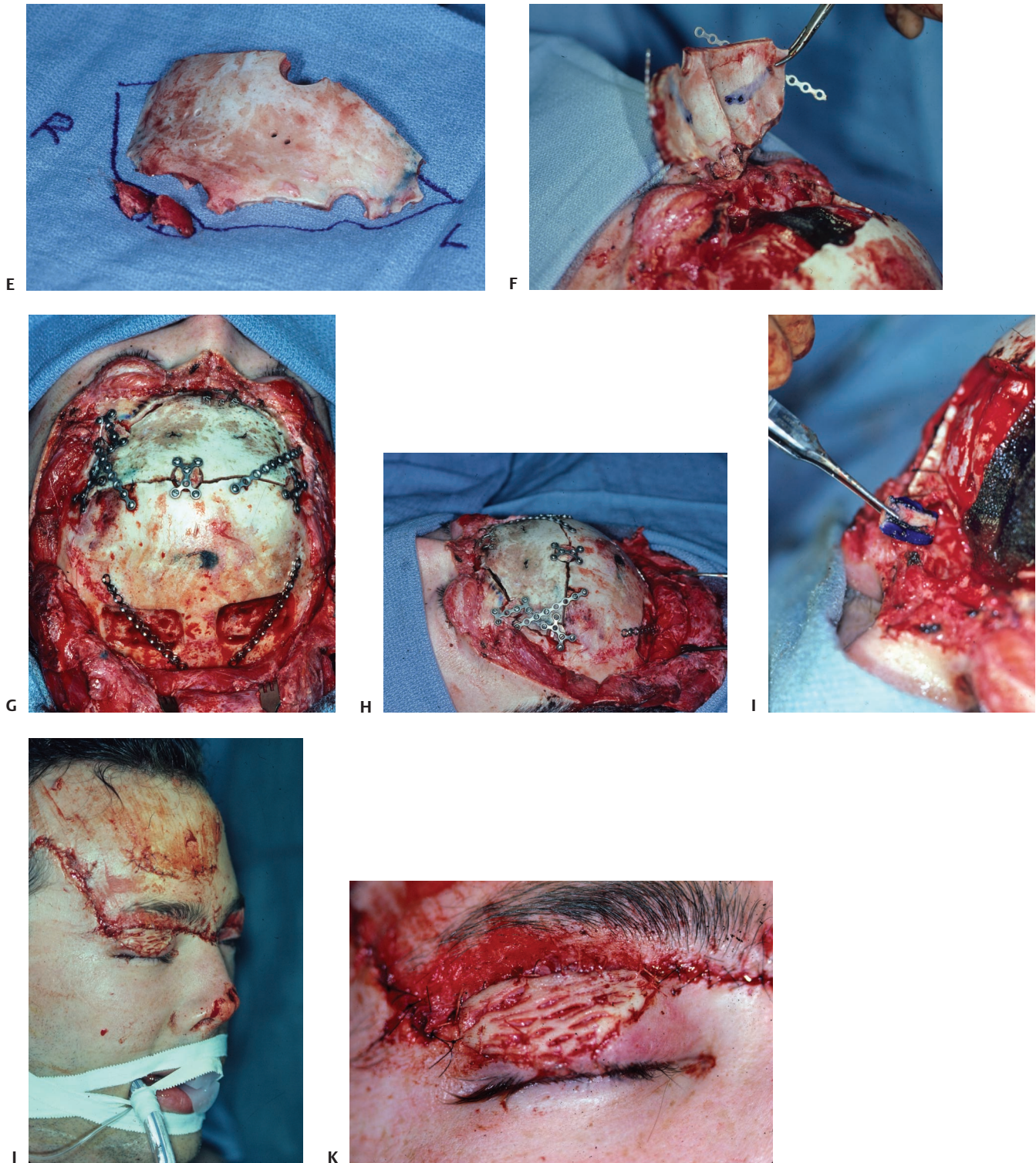


Fig. 6.37 (Continued) (E–K)



Fig. 6.37 (Continued) (L-M)

■ Key Points

Basilar fractures of the cranial vault may exist independently or may be connected in a cascade from anterior to posterior, beginning at the frontal boss, passing through the sphenoid sinus, then ending in the temporal or occipital bones. Foramina (OLS) in the greater wing of the sphenoid near the temporosphenoid junction serve as end points (for localized, basilar fractures) or serve as through points in pancraniobasilar fractures that traverse the skull base. In their transit through the skull base, these fractures may trigger significant collateral damage and complications, including frontomucopycele, sinusitis, CSF leak, and cranial nerve injury. Some collateral injuries merit intervention, some “merely” close observation.

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7 The Medial Orbital Frame and Central Upper Face (Nasal-Nasoseptal, Nasomaxillary, Orbitoethmoid, and Orbitosphenoid Complex)

With contributions by John H. Phillips

■ Part 1. Surgical Anatomy and General Considerations

The central upper face is at the intersection of the cranium and face and may be divided into four compartments: *nasal-nasoseptal*, *nasomaxillary*, *orbitoethmoid*, and *orbitosphenoid*. Part is exposed (the nasal-nasoseptal), as cartilage and nasal bones project beyond the plane of the face. A second part (the nasomaxillary) is protected by serrations of the nasofrontal bony suture at the base of the frontal boss and by thick buttresses, constituting the medial orbital frame. And the third and fourth segments of the central upper face (lacrimal, ethmoid, and sphenoid bones) are relatively sheltered and couched beneath the frontal boss (**Fig. 7.1A,B**).

The Concept of Central Upper Facial Compartments

Support for this arbitrary compartmentalization into four segments is substantiated by embryologic, histologic, anatomic, and physiologic considerations¹⁻⁴ (**Fig. 7.2**).

The pathomechanics of central upper facial injury also seem to corroborate this arbitrary compartmentalization, as the nasal-nasoseptal, nasomaxillary, orbitoethmoid, and orbitosphenoid compartments progressively and serially collapse or fracture as load stresses cascade to ever more penetrating depths.⁵⁻¹¹

The Nasal and Nasoseptal Compartment

The nasal bones and cartilages are cradled by three of the seven craniomaxillofacial buttresses of the midface that arise from the palatal platform. As such, the anterior medial buttresses (the frontal processes of the maxilla),



Fig. 7.1 (A, B)

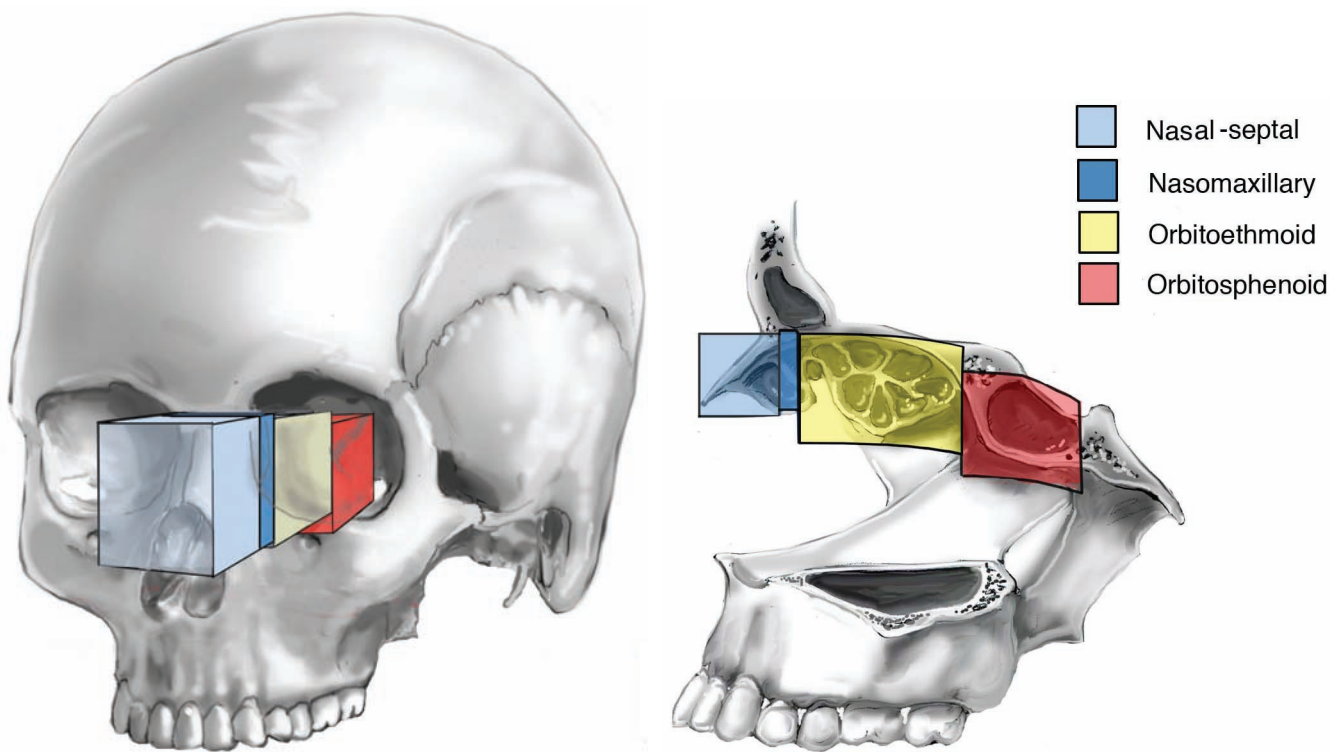


Fig. 7.2

the posterior sagittal buttress (vomer-sphenoidal-frontal buttress), and palate (see Chapter 4) form a triangulated platform on which the nasal bones and nasal cartilages reside. As noted in Chapter 1, Cryer considered the posterior sagittal buttress to be a “flying” buttress, spanning the palate and cranial base to support the floor of the sphenoid sinus.

The nasal-nasoseptal compartment is further divided into subcompartments or vaults: lower vault (I), middle vault

(II), and upper vault (III). Each vault contains a defined portion of the nasal septum.¹⁰ An inferior strut of cartilage is in the lower vault, and the cartilaginous midseptum is included in and is continuous with both lateral nasal cartilages. The superior strut and adjacent bone of the ethmoid plate are beneath the nasal bones in the upper vault. The latter ascends to the base of the cribriform plate (**Fig. 7.3**).

In the distal vault (I) are the greater alar cartilages, the septal angle, and the *caudal strut* of the nasal septum.

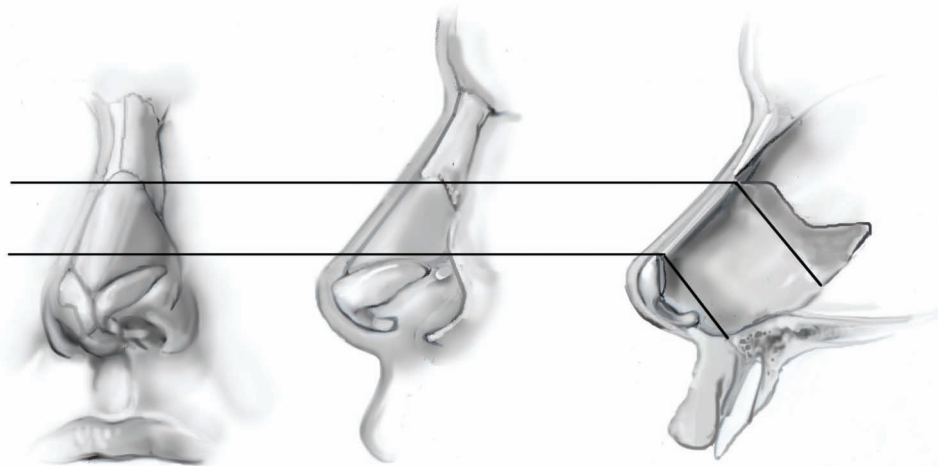


Fig. 7.3

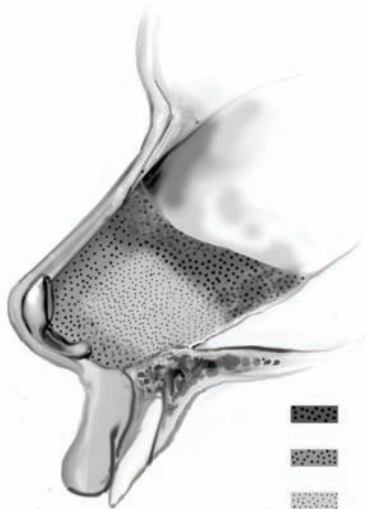


Fig. 7.4

In the middle compartment (II) are the lateral nasal cartilages, the septal *dorsal strut*, and a thin, *central partition* of cartilage that rests on the maxillary crest. In the proximal vault (III) are the nasal bones, the thickened *superior strut* of septal cartilage, and the keel-like vomer.

The cartilaginous struts (caudal, dorsal, and superior) and a thin central partition are depicted. The lateral nasal cartilages, dorsal strut, and central partition are in continuity in the mid-septum (middle vault). The superior strut in the upper vault is thick relative to other areas of the septum and is embryologically in continuity with the ethmoid plate. The superior strut and the underlying vomer are “key” structures¹¹ in the event of trauma to the upper vault of the nose (Fig. 7.4).

A fascial aponeurosis, the *domal suspensory ligament*, interconnects the alar cartilaginous components and anchors the lower vault to proximal structures. The fascial sleeve is Y-shaped and envelops the greater and minor cartilages, sweeping from lateral to medial. The portion of fascia that anchors the lower vault to the underlapping lateral cartilage is lax and delicate. In other areas, particularly between tip-identifying points (the domes and columellar jut), the fascia is thick and tendinous^{10–13} (Fig. 7.5).

The upper border of each nasal bone is deeply serrated for articulation with the *nasal notch* of the frontal bone at the base of the frontal boss. The inferior margin of the nasal bone is thin and gives attachment on its undersurface to the upper lateral cartilage of the nose by way of the *dorsal suspensory ligament*. The lateral border of each bone is also serrated, beveled at the expense of the inner surface above and of the outer below, to articulate with the frontal process of the maxilla.¹⁴ The medial border, notably thicker above than below, articulates with its fellow of the opposite side.

The biomechanical advantage of the upper vault, favoring distribution of equilibrium circuits of stress, is clear: it is stabilized by early ossification of the internasal suture, girded by merger with the frontal processes of the maxilla

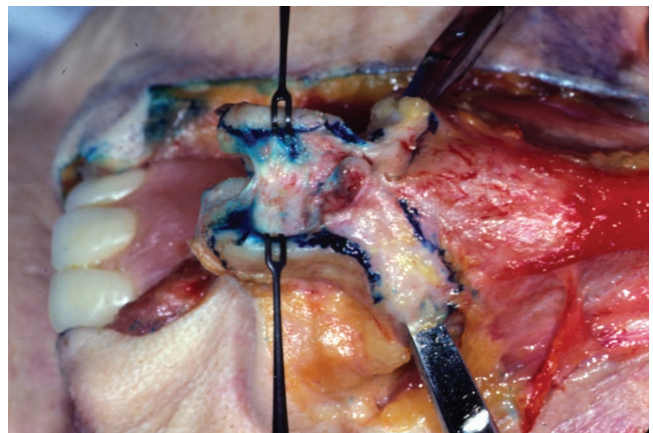


Fig. 7.5

(transitioning to the nasal sidewalls and the medial components of the orbital frame), and locked into position at the midline by the heavy serrations, at the nasofrontal suture (Fig. 7.6A,B).

The Nasomaxillary Compartment

The frontal processes of the maxilla form the second compartment of the central upper face. The frontal processes:

- Provide the infrastructure for registration of the nasal bones
- Engage the nasofrontal suture and base of the frontal boss
- Form the medial portion of the orbital frame
- Secure attachment of the medial canthal tendon and, thus, the upper and lower eyelids

The medial canthal (*palpebral*) tendon attaches to the frontal process of the maxilla just in front of the lacrimal groove. The attachment may be compromised in fractures of the midcompartment of the central upper face. The tendon is approximately 4 mm in length and 2 mm in breadth; crossing the lacrimal sac, it divides into two parts, upper and lower, each attached to the medial end of the corresponding tarsus.¹⁴ Telecanthus may follow nasomaxillary fractures and lateral (outward) displacement of the medial canthal tendon and eyelids.

The maxillae are the second largest bones of the face and create, by their union, the upper jaw. Each maxilla contributes to:

- The boundaries of three cavities (the roof of the mouth, the floor and lateral wall of the nose, and the floor of the orbit)
- Two fossae (infratemporal and pterygopalatine)
- Two fissures (the inferior orbital and pterygomaxillary fissures)¹⁴

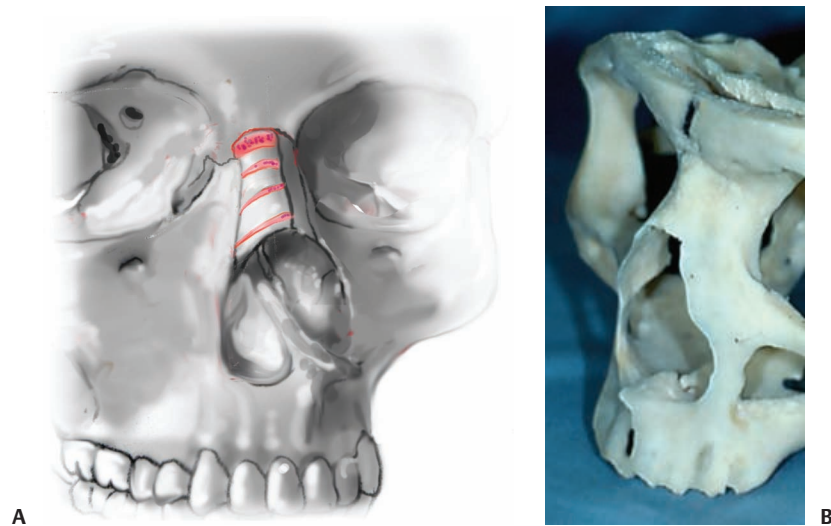


Fig. 7.6 (A, B)

The lateral palpebral raphe is a much weaker structure than the medial canthal tendon.^{15,16}

The Orbitoethmoid and Orbitosphenoid Compartments

The *lacrimal*, *ethmoid*, and *sphenoid* bones constitute the third and fourth of four compartments of the central upper face. Each is relatively sheltered beneath the (horizontal plate of the) frontal bone, deep to the nasofrontal processes of the maxilla, and well within the orbit. Each bone has key craniofacial articulations:

- The *lacrimal* articulates with 4 bones: 2 of the cranium (the frontal and ethmoid) and 2 of the face (maxilla and inferior nasal turbinate).
- The *ethmoid* articulates with 13 bones: 2 of the cranium (the frontal and sphenoid) and 11 of the face—the 2 nasal bones, 2 maxillae, 2 lacrimals, 2 palatines, 2 inferior nasal conchae, and the vomer.
- The *sphenoid* articulates with 12 bones: 4 single—the vomer, frontal, ethmoid, and occipital; and 4 paired—the palatine, zygomatic, temporal, and parietal. It also sometimes articulates with the tuberosity of the maxilla.

The *lacrimal*, like the frontal process of the maxilla, is serrated for intimate articulation with the thickened frontal bone above. A near-vertical, J-shaped ridge (the *lacrimal crest*) subdivides the lacrimal bone. In the front half is the *lacrimal fossa*, the upper part of which is hollowed to house the lacrimal sac and the lower part of which lodges the nasolacrimal duct. The portion behind the crest is smooth and forms part of the medial wall of the orbit; it is directed parasagittally and is not convexly contoured into the orbit, in contrast to the *ethmoid jut*

of the lamina papyracea (see Fig. 8.7 in Chapter 8). The *ethmoid bone* is situated at the anterior base of the brain, between the two orbits, at the roof of each nasal vault and contributes to both of these cavities.¹⁴ The ethmoid bone has four parts: a horizontal component (the *cribriform plate*), a *perpendicular plate* (constituting part of the nasal septum), and two *lateral masses* or (ethmoid) labyrinths.^{14,16} The cribriform plate is received into a narrow notch of the frontal bone (appropriately called the *ethmoid notch*).

Each *lateral mass* (ethmoid labyrinth) is hinged from the parasagittal portion of the cribriform plate and consists of several thin-walled cellular cavities, the *ethmoidal cells*. The ethmoid cells are arranged in three groups, *anterior*, *middle*, and *posterior*, and are interposed between two plates of bone; the lateral plate forms part of the orbit (portion of the medial wall), and the medial plate forms part of the corresponding nasal cavity.

Projecting downward from the midline of the cribriform plate is the thin, delicate perpendicular plate (*lamina perpendicularis*). The plate articulates with the spine of the frontal bone, the midline crest of the nasal bones, and the sphenoidal crest; it is housed in the groove of the vomer below. The ethmoid plate is continuous with the *superior strut* of nasoseptal cartilage, also in the midline.

Projecting upward from the middle of the cribriform plate is a thick process resembling a cock's comb, the *crista galli* (see Fig. 6.5). The crista and two *ala*, though abbreviated and stubby, tightly engage the frontal bone.

On either side of the crista galli, the cribriform is narrowed, deeply grooved, and, at the front, fissured, to be occupied by a key attachment of *dura mater*. With fracture of the cribriform, the crista and ala may be displaced, and the dura at this location may be torn, allowing cerebrospinal fluid leak (rhinorrhea).^{17,18}

The body of the sphenoid is cuboidal in shape and is hollowed out to form two large cavities (the sphenoid sinuses, with robust walls, floor, and roof) but without the cross-struts found in the ethmoid labyrinth. The sphenoid presents a prominent ethmoidal spine (to engage the posterior reach of the cribriform plate) and lesser and greater wings that house the optic canal and numerous foramina and create the buttresses of the orbital apex. The clivus of the sphenoid slopes downwardly to interface with the basilar portion of the occipital bone.

The Concept of the Orbitoethmoid and Orbitosphenoid Buttresses

The *orbital plate of the lacrimal bone* descends to engage the *orbital plate of the maxilla* (in the anterior floor of the orbit) and the *lacrimal process of the inferior nasal turbinate*, creating the orbitoethmoidal buttress (**Fig. 7.7A,B**).

The *lesser wing of the sphenoid* (medial to the *outlet of the optic foramen*), the *anterior wall of the sphenoid sinus*, the *orbital process of the palatine bone* (in the posterior floor of the orbit), and the *posterior wall of the maxillary sinus* create the orbitosphenoidal buttress.

The Concept of Microbuttresses of the Ethmoid Sinus

An irregular myriad of internal microbuttresses (that we refer to as “cross-struts”) are embedded within the walls, roof, and floor of the ethmoid labyrinth, or traverse the labyrinth from wall to wall. The cross-struts have been referred to as “septae” and the ethmoid labyrinth therefore as “septate.”¹⁹ The cross-struts become thick, longer, and greater in number from anterior to posterior ethmoid. These cross-struts are absent from the sphenoid sinus (**Fig. 7.8A,B**).

Nasal-nasoseptal, Nasomaxillary, Orbitoethmoid, and Orbitosphenoid Architecture in Children

The nasal cartilages of children are thin, and the parameters are diminutive. Damage to the alar cartilages (of the nasal tip) or avulsion of the lateral nasal cartilages after blunt trauma is therefore *uncommon*. The small nasal bones in children do not fuse at the midline nor do they join with the frontal processes of the maxilla until late adolescence. Each nasal bone, therefore, stands relatively alone and tends to fracture independently of the other when precise force is applied (**Fig. 7.9**).

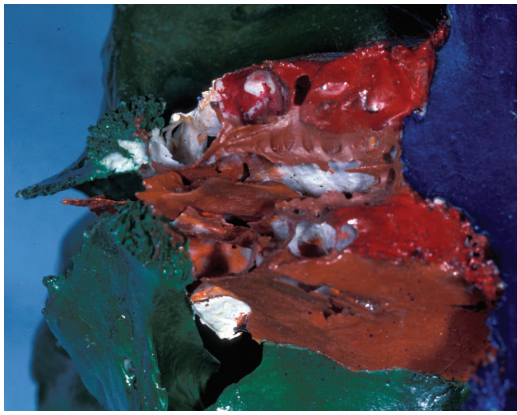


A



B

Fig. 7.7 (A, B)



A



B

Fig. 7.8 (A, B)



Fig. 7.9

In the child, the frontal processes of the maxilla are vertically foreshortened, and the orbitoethmoid and orbitosphenoid complexes are equally underdeveloped, awaiting concomitant growth of the maxilla and the anterior paranasal sinuses. Fractures of the upper central face it follows are unusual in children.

■ Part 2. Operative Technique and Exemplary Repair

Permutations of *nasal-nasoseptal*, *nasomaxillary*, *orbitoethmoid*, and *orbitosphenoid* injury in the adult are evident clinically and in the laboratory after induced trauma. The structure of the nose and frontal processes of the maxilla, and orbitoethmoid, and orbitosphenoid complexes (with recognized regional differences in bone, cartilage and fascia) warrants that distal injuries will differ from those more proximal.

The *nasal-nasoseptal* injury may be confined to soft tissue and cartilage, such as the alar cartilages, lateral nasal cartilages, and nasal septum, in great part due to the resilience of cartilage and the interalar (nasal tip) fascial aponeurosis.¹⁰ The nasal bones per se avoid injury or may be minimally harmed by low-velocity impact; more often than not, however, fracture of one or both nasal bones extends to involve the anterior edge of the frontal processes of the maxilla,¹¹ where the maxillary bone is thin, tapered, and nearly equally vulnerable to damage. In radiographic reports, involvement of the frontal processes may be minimized.

As velocity of impact increases, more extensive involvement of the frontal processes of the maxilla is witnessed, and the fractures become *nasomaxillary* in their reach. The nasomaxillary fragments are key to the repair of the medial orbital frame and are best aligned before repair of the inferior orbital rim and zygoma. Failure to first restore the anatomic position of the medial orbital frame inappropriately biases realignment of the inferior orbital frame and zygoma.²⁰ The medial canthal ligament may be displaced or separated from its mooring, particularly with comminution.

As load forces extend beyond the frontal processes of the maxilla, the impact triggers a proverbial “house of cards,” and the fractures become *orbitoethmoid* and *orbitosphenoid* in scope. The frontal processes of the maxilla and lacrimal bone unhinge from the frontal boss; the usually tight fit at the nasofrontal suture defaults. The anterior orbitoethmoid buttress (linking the posterior portion of the lacrimal bone, inferior turbinate, and anterior medial maxillary) wall succumbs. The bilge of the orbital floor (see Chapter 8), the roots of the superior and middle turbinates, and the ethmoid labyrinth, all hinged from the

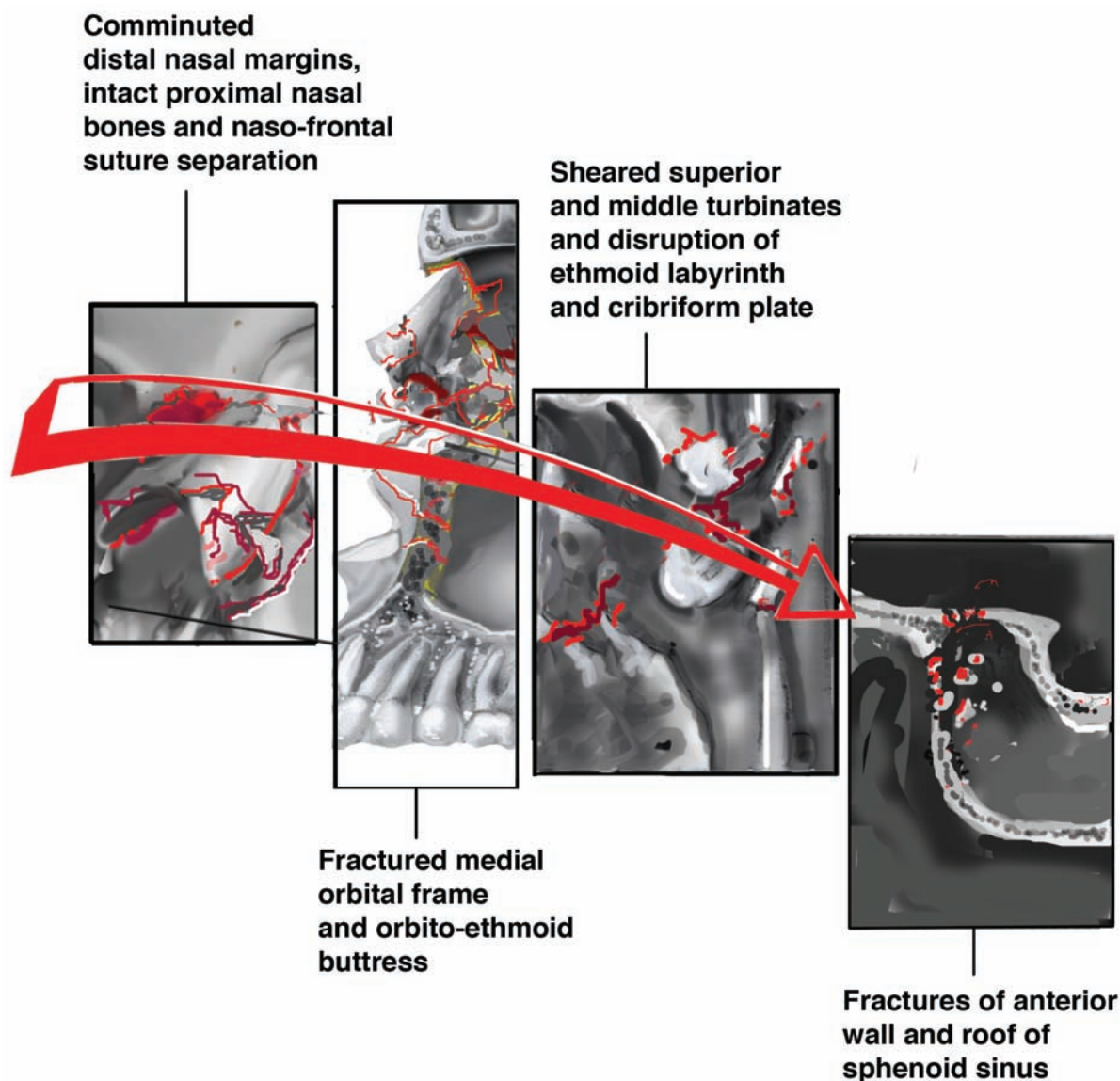


Fig. 7.10

parasagittal aspect of the cribriform plate, are sheared from their attachment. The struts (“microbuttresses”) within and across the walls, roof, and floor of the ethmoid sinus collapse and buckle (Fig. 7.10).

The *orbitosphenoid buttress* (lesser wing of the sphenoid medial to the outlet of the optic foramen, the orbital process of the palatine bone, and the posterior wall of the maxilla) is but a short distance away.

In its most extreme presentation, the fractures through the sphenoid become basilar to end at one of several foramina in the greater wing of the sphenoid (foramen ovale, foramen lacerum, foramen spinosum, or the carotid canal [see Chapter 6]). Further, injuries this extreme often compromise the optic canal and the content of various foramina at the orbital apex.

Management of Fractures of the Central Upper Face in Days Past

Fractures of the central upper face have not always been managed the way they are today. In Ancient Egypt, for example, nasal fractures were among “those to be treated,” as opposed to “those not.” The nostrils were first cleansed of blood and debris, and the fragments were then to be reduced by digital manipulation. Finally, linen plugs were to be inserted into each nasal vault, and oil-soaked linen wraps were added to provide support.

Instruction regarding central upper craniofacial fractures was explicit. Case XIII of the Smith Papyrus admonishes the practitioner, in the presence of “a compound fracture . . . of the nose, . . . that crepitates under thy fingers . . . ,

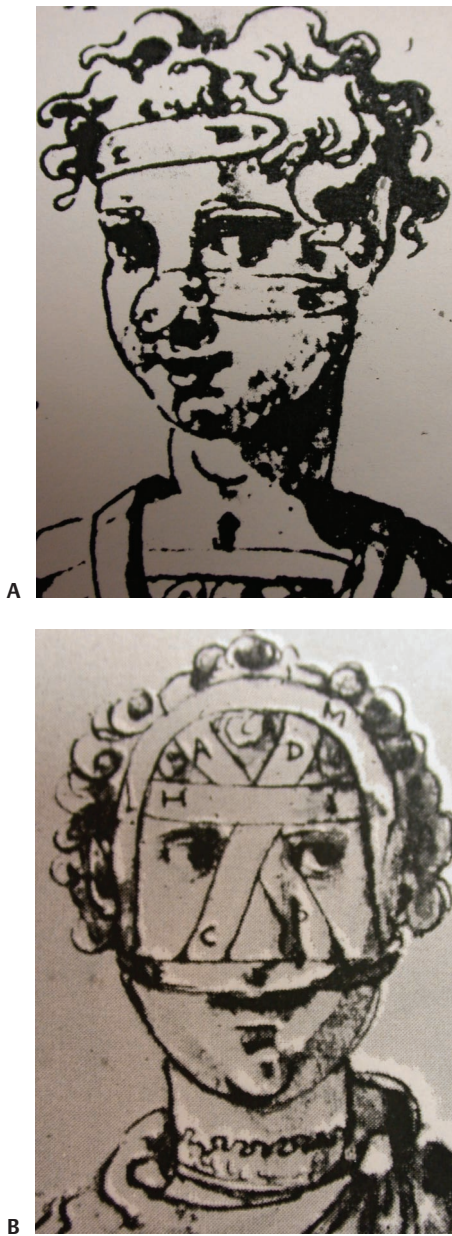


Fig. 7.11 (A, B)

though should say concerning him: One having a smash in the nostril is an ailment not to be treated."

These Egyptian dictates were followed in kind in Ancient Greece and Ancient Rome, but greater emphasis was placed on the application of oil-soaked linens to stabilize the fragments after manipulation. The dressings by Hippocrates and by Menecrates, respectively, were favorites over the centuries²¹ (Fig. 7.11A,B).

During the European Wars (1852 to 1870) and World War I (1914 to 1918), management of nasal fractures differed little from that offered in ancient times.²² During World War II, the Korean War, and the Vietnam Conflict, manipulation

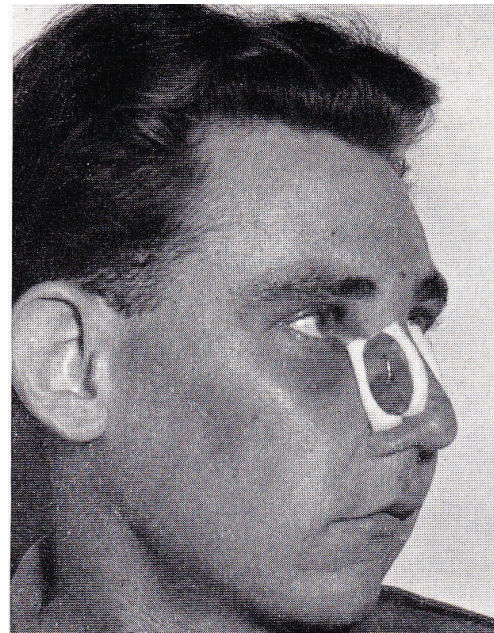


Fig. 7.12 With permission: Rowe NL, Killey HC. Fractures of the nasal region, frontal sinus, and para-nasal air-sinuses (Chapter 16). In: Rowe NL, Killey HC. *Fractures of the Facial Skeleton* (2nd ed.). Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins; 1970:Fig. 16.25, p. 26. All rights reserved.

of the fragments with Walsham or Asche forceps was favored, followed by the application of linen dressings or tin nasal splints reinforced with gutta-percha.²³

In the presence of comminution and instability, trans-nasal horizontal mattress stainless steel wire was passed beneath the fragments and through the septum, using a curved Hagedorn abdominal cutting needle. The wire was tied over lead plates at each sidewall of the nose. In cases where outward and upward suspension was desired, a plaster of Paris headcap was chosen as an adjunct (Fig. 7.12).

Preoperative Assessment and Indications for Repair

Clinical Presentation

Because the nose projects beyond the plane of the craniofacial skeleton, injuries to nasal structures are common. The nasal injury may be confined to soft tissue (such as the *dorsal suspensory ligament*) and cartilage (such as the alar cartilages, lateral nasal cartilages, and nasal septum), and the nasal bones may be minimally involved after low-velocity impact, thus *nasal-nasoseptal*. More often than not, however, when load forces are sufficient, fracture of one or both nasal bones extends to involve the edge of the frontal processes of the maxilla, where the maxillary bone is thin, tapered, and vulnerable.

When load forces reach the thicker portions of the frontal process of the maxilla, the fracture is said to be *nasomaxillary*, and attachment of the medial canthal tendon is put at risk. If

the frontal processes do not withstand the impact, the next compartment (the *orbitoethmoid* complex) becomes vulnerable to comminution, particularly the *orbitoethmoid buttress*. Fracture of all three compartments (naso-nasoseptal, nasomaxillary, and orbitoethmoid) is colloquially referred to as a nasoethmoid fracture. When load forces fracture the orbitosphenoid buttress, fractures, as noted previously, may extend to the sphenoid sinus and center of the skull base.

Swelling and ecchymosis are generally proportional to the extent of the injury and may camouflage the more subtle injury, such as avulsion of the dorsal suspensory ligament and lateral nasal cartilage from the *undersurface* of the nasal bone. Avulsion may be apparent only with serial preoperative examination, during surgery (after reduction and realignment of fractured bone), or after months of postoperative healing.

Spraying the mucosa of the nasal vault with vasoconstricting agent and examination with a magnifying otoscope or fiber-optic nasal scope favors the discovery of septal cartilage and ethmoid plate deflection, rents in the nasal mucosa, or nasoseptal hematoma. Blood confined to the plane anterior to the orbital septum (beneath the fascia of the periorbital musculature) presents as a “spectacle hematoma.”

Foreshortened nasal bones are more vulnerable to impact than an upper nasal vault of normal proportion. The nasal bones are foreshortened in the patient with *short nasal bone syndrome*, and the lateral nasal cartilages are relatively elongated.¹⁰

This atypical nasal architecture is vulnerable, and greater offloads are dispersed to and from the lateral nasal cartilages, the proximal septum, the nasofrontal suture, and the frontal process of the maxilla. Rupture of the dorsal suspensory ligament and nasal cartilage avulsion from the undersurface of the nasal bone(s) is more commonly noted, and unilateral nasomaxillary fracture is more frequently present. Involvement of the orbitoethmoid buttress in patients with “short nasal bone syndrome” is probable (Fig. 7.13).

A saddle nose deformity commonly follows comminuted nasal and nasomaxillary fracture. The “saddle” may be



Fig. 7.13

more apparent when the anterior orbitoethmoid buttress “gives way,” the ethmoid *lateral masses*¹⁴ (cross-struts) collapse, and the medial walls of the orbit buckle, creating a flattening of the central upper face. In adolescence and young adulthood, these changes may misleadingly appear to be unilateral in the presence of edema.

Initial inspection focuses on the position (height, projection, and width) of the nasal tripod.²⁰ After nasomaxillary and particularly after orbitoethmoid comminution, the nasal pyramid is observed to be displaced inwardly as the pyramid is engulfed by the central void. The nasal pyramid is displaced as an *intact* unit in the adult if ossification of the internasal suture has occurred associated with a loss of nasal height, flattening of the nasal dorsum, and loss of distal septal support. Distal nasal bones, as illustrated in Fig. 7.14, are usually comminuted. *The intact proximal nasal bones and medial orbital frame are driven downward and backward*, disrupting the orbitoethmoid buttress (created by the orbital plate of the lacrimal, the lacrimal process of the inferior turbinate, and the upper medial wall of the maxillary sinus) and the adjacent medial orbital wall. A frontal blow of sufficient intensity may fracture the orbitosphenoid buttress and the anterior wall of the sphenoid sinus, further deepening signs of central upper facial collapse (Fig. 7.14).

Increased intercanthal distance, or telecanthus, is characteristic and the next focus of examination. Gentle palpation reveals a discontinuity or “step-off” of the medial orbital frame, either below or above the medial canthal tendon. Firm pressure over the fragmented medial orbital frame may provoke mobility and a palpable “click.” Step-offs may be multiple in the presence of comminution. The integrity of the medial canthal tendon may be confirmed under local anesthesia preoperatively by inserting instruments high in the nasal vault, but the exam is usually deferred so that it may be correctly achieved under general anesthesia and careful use of instrumentation.²⁴

Basic ocular assessment is achieved in five steps, avoiding meaningless generalities such as “examination grossly normal” or “pupils equal, round, reactive to light and accommodation,” as follows:

1. Distant and near vision, with one eye occluded, is noted; if vision is so challenged that fine print cannot be read, the ability to count fingers should be noted.
2. The size and shape of the pupils is charted; reaction of the pupils to bright light, particularly the presence or absence of the afferent pupillary defect, is critical; direct pupillary response to alternating light, as it passes briskly between the two eyes, is readily tested.
3. Clarity of the cornea and anterior chambers is recorded, searching for hemorrhage and asymmetries.
4. Direct ophthalmoscopic examination, looking for the presence of a red reflex, the macula, the optic nerve head, and the absence of enfolding of the retina.
5. Ranges of motion in both vertical and horizontal gaze.^{25–29}

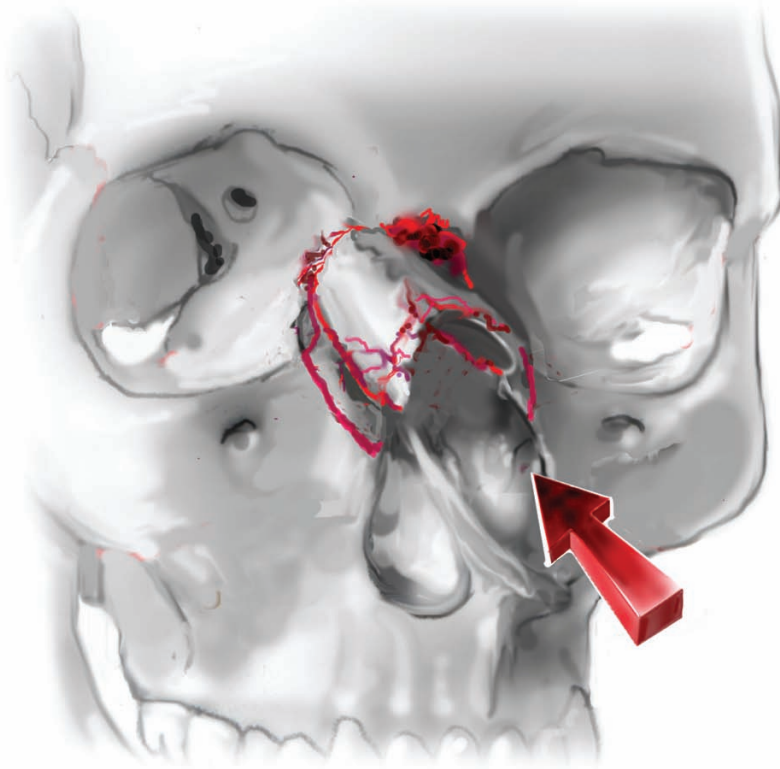


Fig. 7.14

Abnormalities in the five-point assessment would lead to ophthalmologic consultation.

Radiographic Assessment in Children

Direct blows over the bridge of the nose during childhood tend to create a fault in the midline, cleaving the inter-nasal suture. In this circumstance, a flattened dorsum is apparent with dramatic loss of projection. Radiographs in this age group reveal that the lateral aspect of one or both of the nasal bones is displaced and lays on an intact frontal process of the maxilla. Dingman and Converse refer to this feature in children as an “open book fracture”¹¹ (Fig. 7.15).

An underlying *nasomaxillary* or *orbitoethmoid* fracture is seldom present in children. The internasal and nasofrontal sutures usually absorb the stress of impact in adolescence, and load forces are seldom the result of high-velocity.

Radiographic Assessment in Adults

Radiographic Classification of Nasal-nasoseptal Fracture

The lower nasal vault consists of the greater alar cartilages and inferior strut of the septal cartilage. Upon impact,

there are three predominant patterns of injury: septal angle deflection, inferior buttress (“zig”) deflection, and nasal lobule (tip) collapse.¹⁰

The middle nasal vault has four biomechanical parts: the conjoined lateral nasal cartilages and the underlying septal cartilage (dorsal buttress and central partition). Upon

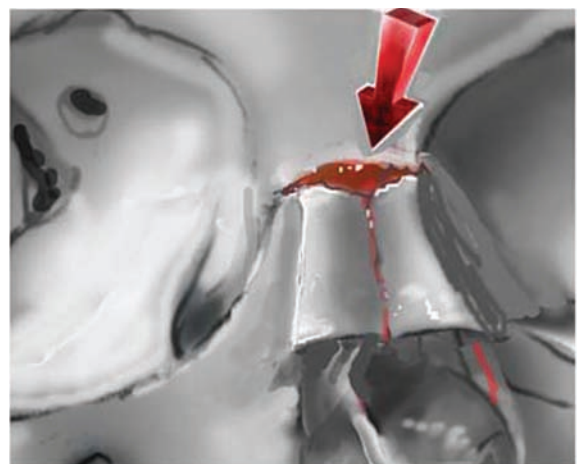


Fig. 7.15

impact, two dominant patterns emerge.¹⁰ When injury occurs in the *middle* vault, the septal cartilage buckles, creating a notable, “zig-zag” deformity; alternately, after a direct blow to the mid-dorsum, the dorsal septal strut may collapse, and the bone of the perpendicular plate of the ethmoid comminutes in a “starburst” pattern. The lateral nasal cartilage may be avulsed from its attachment to the undersurface of the nasal bone (**Fig. 7.16A,B**).

In *proximal* vault injuries, the nasal bones and adjacent frontal processes of the maxilla share the cumulate load forces. Septal deviation is accentuated by deflection of the superior strut of septal cartilage, the vomer, and more extensive injury of the ethmoid plate (that may reach the cribriform plate above). Four patterns of proximal injury are common.⁵ Distal nasal “wing” fractures usually follow low-velocity impact initiated from the side, but bilateral displacement is noted when the thicker, more proximal nasal bone is involved.

A majority of nasal fractures (some 80%) occur near the “junction” of the thin and the thicker, proximal bone.¹⁰ The fracture pattern is often *not* the same on each side, as a majority of injuries are delivered off center and at an angle.^{5,30,31} In a typical combination, the fracture is comminuted on the side nearest the impact, but features a “greenstick” fracture on the *opposite side*. On radiographs (particularly computed tomography with three-dimensional reformats), the greenstick fracture involves a single, large bone fragment (**Fig. 7.17A–B**).

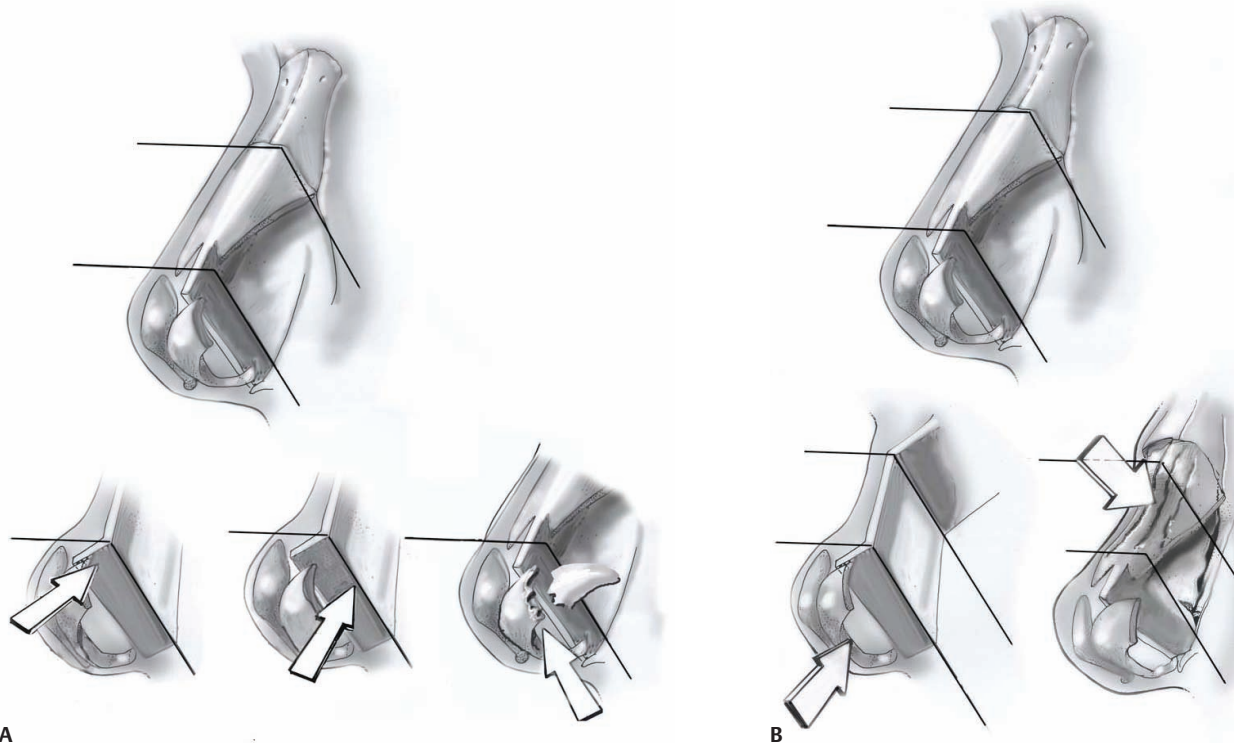
Radiographic Classification of Nasomaxillary Fracture

Numerous classifications of nasomaxillary fractures have been tendered. Those by Converse and Smith³² and Markowitz and Manson³³ are based on *the fragment or fragments to which the medial canthal tendon remains attached*. The classification creates an excellent basis for radiographic differentiation, operative exposure, and repair of the injury.

Nasomaxillary fractures are divided into three radiographic groups, after Manson and colleagues^{20,33}:

- Single fragment (Type I)
- Comminution with no disinsertion of the medial canthal tendon (Type II)
- Comminution with disinsertion of the medial canthal tendon (Type III)

In type I fractures, the frontal process of the maxilla is modestly displaced. The fracture that occurs *above* the level of the medial canthal tendon may not create a step-off (to palpation) and is considered to be a greenstick fracture. The fracture *below* the tendon attachment (on the medial orbital frame) is medially displaced toward the nasal vault and becomes vertically oriented. If unrecognized by high-resolution computed tomography (HRCT) and three-dimensional reformatting, this vertical reorientation of (the nasomaxillary portion of) the medial orbital frame may profoundly bias reduction and



A
Fig. 7.16 (A, B)

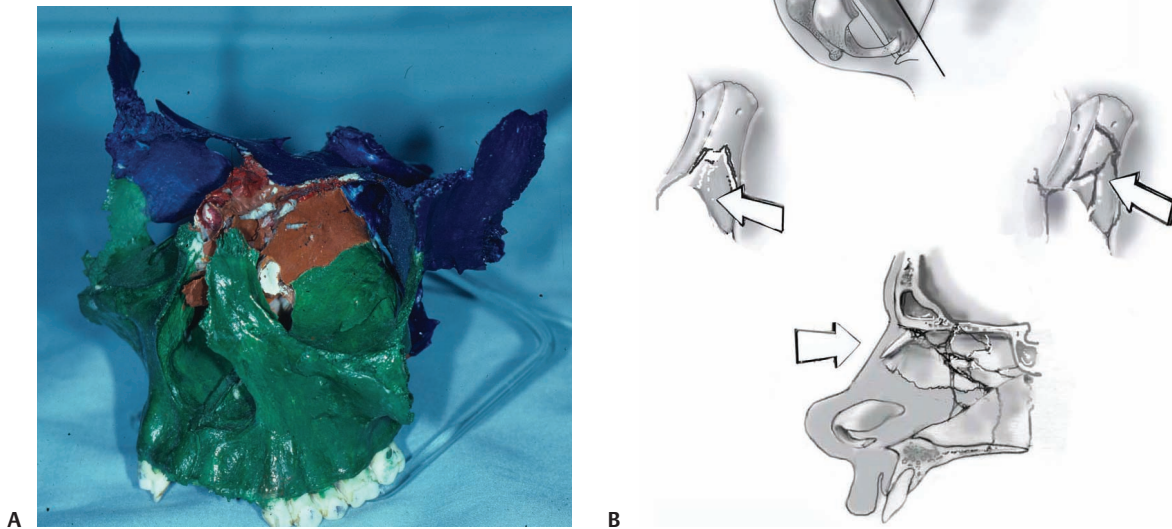


Fig. 7.17 (A-B)

proper realignment of the orbital frame and (the orbital process of) the zygoma (**Fig. 7.18A**).

A subset of type I fracture has been noted: the fracture *above* the canthal ligament is displaced and mobile or the fracture line traverses the nasofrontal suture to the opposite side, creating what Gillies and Kilner^{34,35} and Grant and colleagues²⁰ refer to as a “monoblock fracture.” In the monoblock fracture, the internasal suture withstands the load of impact, and the nasal bones remain an intact composite (**Fig. 7.18B**). In type II fractures, multiple fractures

of the frontal process of the maxilla are present but the attachment of the medial canthal tendon is secure, usually to a large central fragment. Often a combination exists such that a type I fracture is on one side and a type II is on the other. The type III nasomaxillary fracture features comminution of the nasofrontal process of the maxilla with lateral displacement of the medial canthal ligament. The ligament remains attached to a small fragment of bone or rarely is completely avulsed from the bone. Separation at the nasofrontal suture is common (**Fig. 7.18C**).

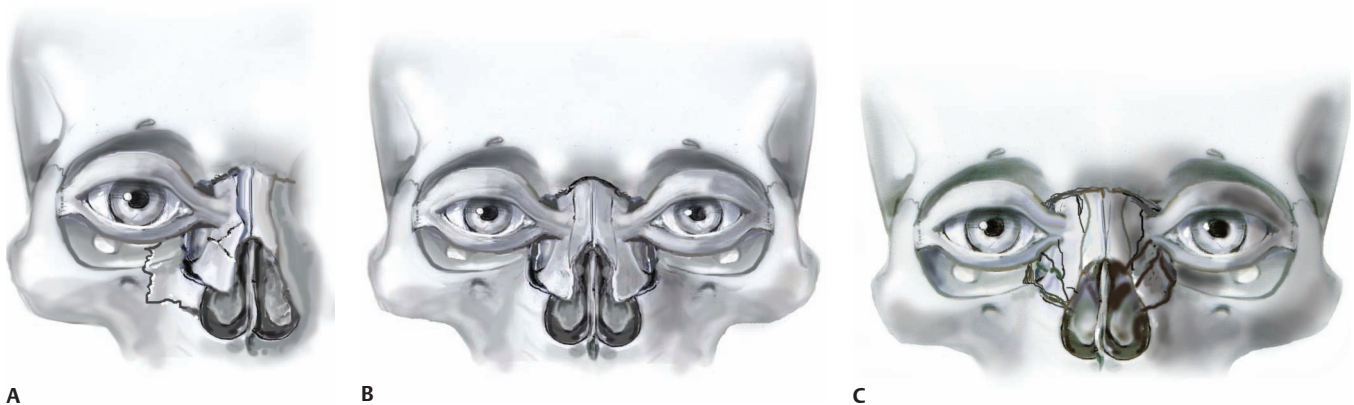


Fig. 7.18 (A-C)

Radiographic Classification of Orbitoethmoid and Orbitosphenoid Fracture

As load forces engage the nose and septum, the thin distal margins of the nasal bones comminute. The nasofrontal suture “gives way” before proximal nasal bone fractures in most instances. The proximal nasal composite is driven posteriorly (see **Fig. 7.14**) and is often apparent on radiographs as a composite. With forced inward entry of the nasal composite, the anteriorly located *orbitoethmoidal buttress* comminutes, and in short order, the *cross-struts* of the ethmoid labyrinth succumb like a proverbial “house of cards.”³⁶ The medial wall of the orbit and/or posterior orbital roof on radiographs exhibit shatter and “blow out.” The *superior and middle turbinates* (as part of the ethmoid complex) are irreversibly displaced in a posterior and inferior direction.

Fracture of the orbitosphenoid buttress is implicated by evidence of fracture of the anterior wall of the sphenoid sinus. As an aid to reconstruction, the palatine bone portion of the *orbitosphenoid buttress*, often remains in anatomic position and can serve as a platform for the placement of bone grafts or commercial implants (see Chapter 8), when reconstructing the orbital floor. Fractures of the posterior wall of the maxilla tend to be nondisplaced on HRCT.

When the four compartments of the central upper face are involved collectively, the central upper face on lateral view is flattened to a single plane (**Fig. 7.19**).

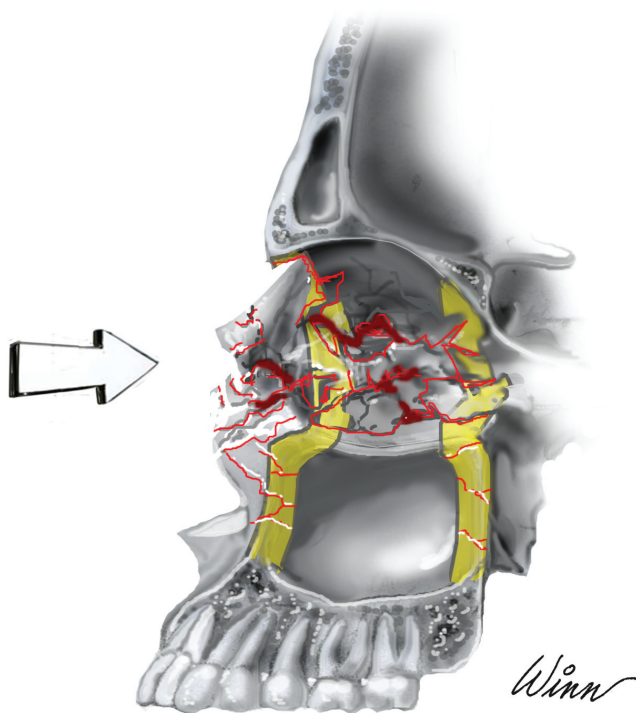


Fig. 7.19

Operative Repair

An algorithm of repair of nasal-nasoseptal, nasomaxillary, and orbitoethmoid fractures follows (**Fig. 7.20**). Much of the orbitosphenoid buttress is beyond operative reach.

Intraoperative Tests to Determine the Extent of Nasal-nasoseptal, Nasomaxillary, and Orbitoethmoid Injury

Intraoperative tests help to declare the extent of injury suggested by radiographic studies and are usually deferred to the operating theater. Furnas and Birrcoll²⁴ describe traction of the lower eyelid to test the competence of the

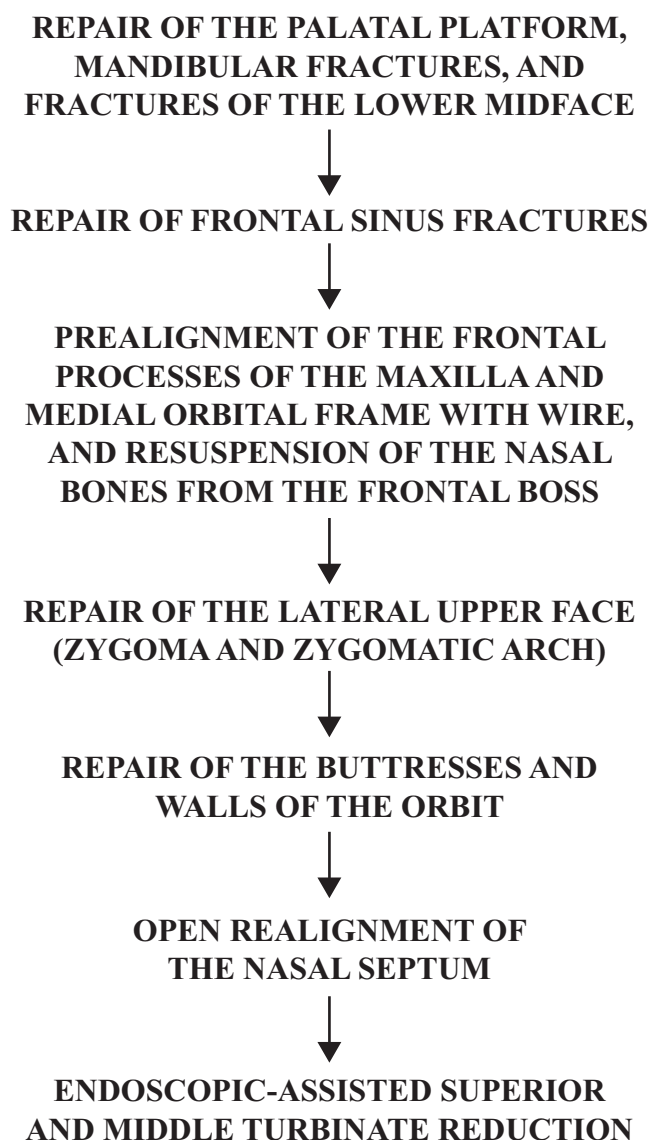


Fig. 7.20

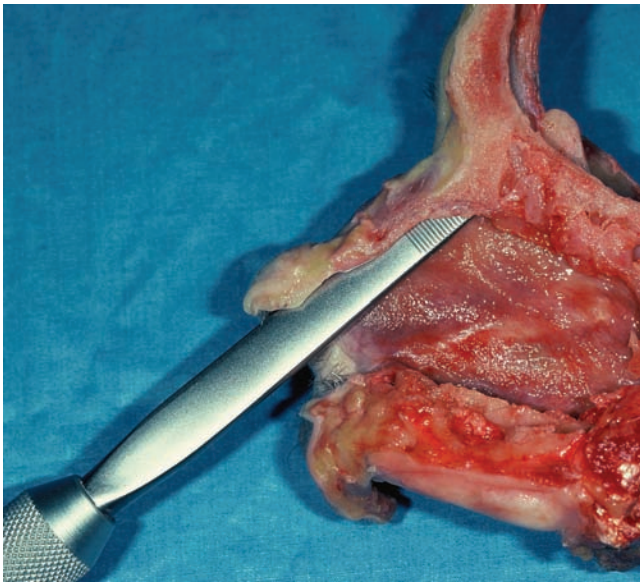


Fig. 7.21

medial canthal tendon, displacement of which typically creates telecanthus. The Furnas-Birrcoll maneuver tests the integrity of the medial canthal ligament fixation to the medial orbital frame. An instrument, such as a Kelley clamp or a Pollock-Dingman elevator, high in the nasal vault assists “bimanual” palpation as the instrument displaces the fractured bone toward the thumb and index finger of the opposite hand³⁷ (Fig. 7.21).

Digital pressure over the dorsum of the nose may trigger further collapse of the underlying, fractured infrastructure. This test was first suggested by Brown and colleagues,³⁸ who used a baton, and Gruss and colleagues,³⁹ who used a digit. The Brown-Gruss provocation has particular significance when it is used selectively to test the competence of *each* nasal compartment^{10,40} under general anesthesia.

Vault compression testing is designated by one or a combination of three Roman numerals,⁴⁰ from distal to proximal. Roman numeral I is assigned to the lower nasal vault, II to the middle nasal vault, and III to the upper. In complex injury, two or more vaults may be involved (Figs. 7.22 and 7.23A–D).

- Lower vault compression (*Brown-Gruss I*) is possible when the septal angle is fractured and the nasal lobule hyperrotates with digital pressure. When the inferior strut of the septum is severely fragmented or when the nasal lobule is violated, inward digital pressure readily triggers collapse of the nasal tip.
- Middle vault compression (*Brown-Gruss II*) is noted when the central aspect of the septal cartilage collapses under pressure of the digit.

- Fractures of the nasal bones and comminution of the frontal processes of the maxilla favor collapse of the upper vault when pressure is applied by the index (*Brown-Gruss III*). The infrastructure telescopes through the orbitoethmoid buttress(es) into the anterior ethmoid sinus(es).

When all three vaults (Brown-Gruss I, II, and III) are compromised, the entire nasal pyramid readily “disappears” from view.

Incisions

The gingivobuccal incision is described in Chapter 4. The coronal incision is detailed in Chapter 3. The lateral canthofornix incision is one of several periorbital options (but the better in many cases) to approach orbital fractures and is described in Chapter 8.

Prealignment and Rigid Stabilization

Lacerations may afford easy entry to limited fractures, but adequate exposure precedes realignment and fixation of many. After periosteal elevation and exposure of the bone fragments, a critical first step of the reduction is identification of the fragments of the medial orbital frame and the medial canthal tendon.^{33,41} The medial orbital frame should progressively curve laterally as it descends, and if found in a vertical position, the bone is realigned in a more anatomical position. The continuity

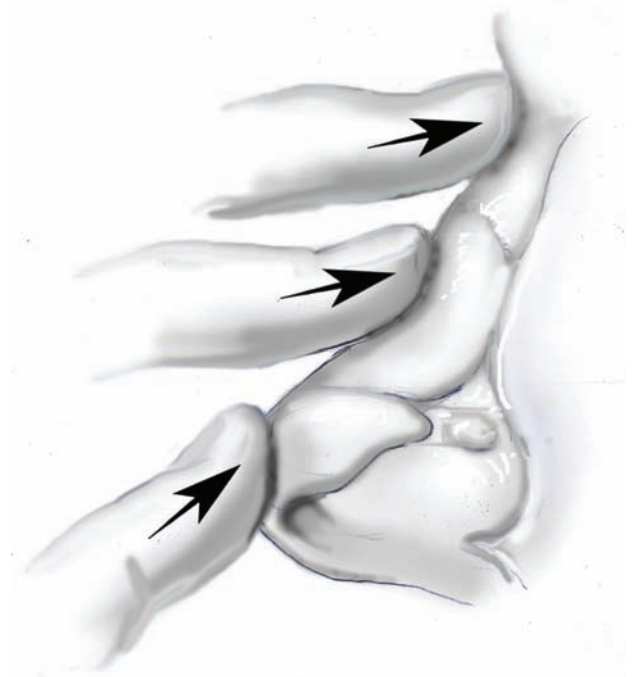


Fig. 7.22

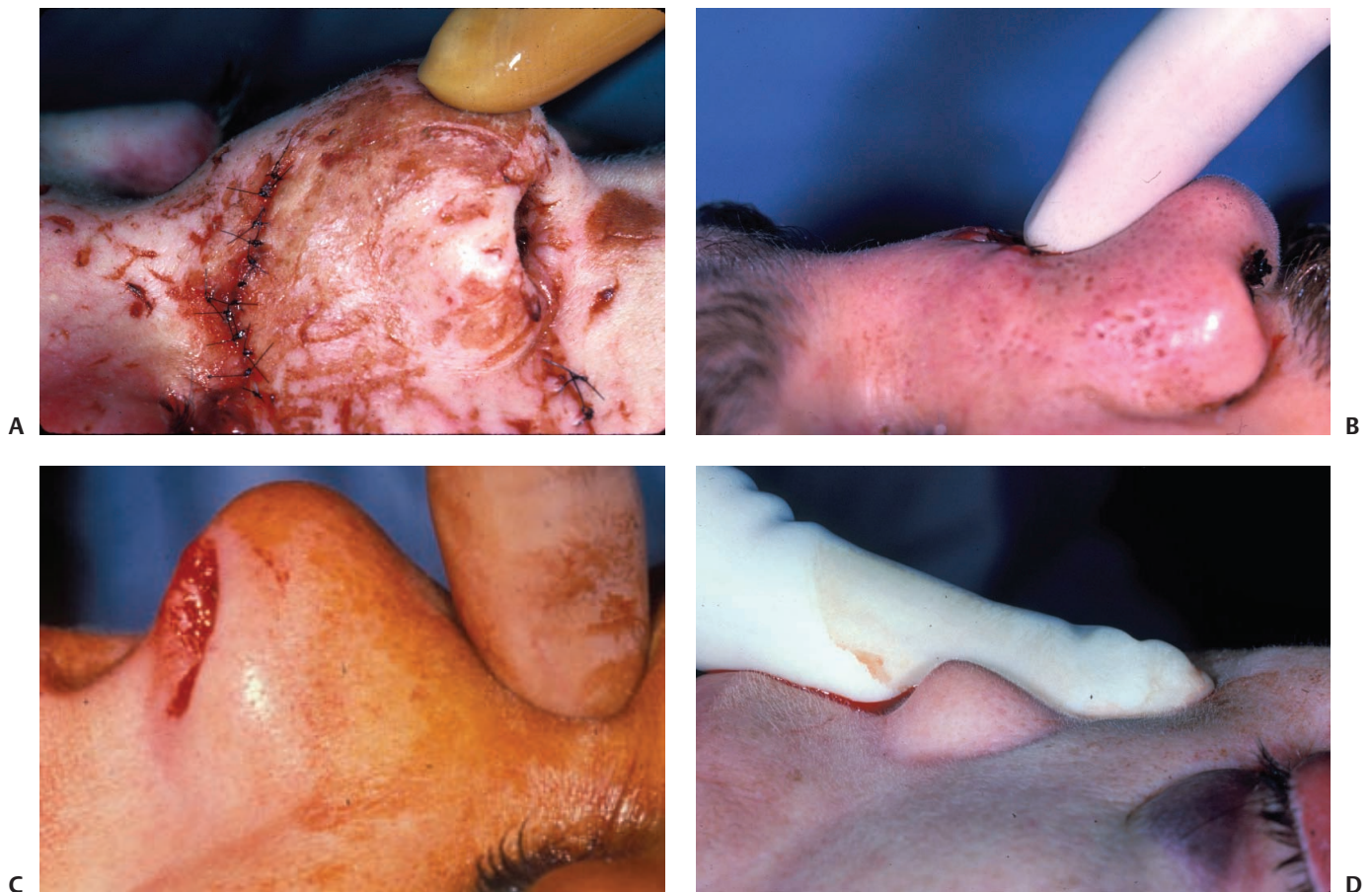


Fig. 7.23 (A–D)

of the medial and inferior orbital rim is established with a lengthy 1.3-mm miniplate; 1.5-mm plates and screws used to assemble the anteromedial buttress of the lower midface may be continued upwardly to reach the frontal boss.

Fine, 25-gauge wire may be used to prealign major fragments or bone grafts (**Fig. 7.24A**).

Type III fractures require prealignment with transnasal titanium wires^{20,33} linking the nasofrontal processes. Application of 1.5-mm plates and screws occurs after correction of telecanthus is assured. Removal of the nasal fragments is first advised to visualize appropriate narrowing of the nasal vault, to create proper angulation and realignment of the frontal processes, and to reestablish relevant intercanthal distance (**Fig. 7.24B**).

Bone grafting is considered in the presence of severe comminution. The graft(s) may bridge the nasofrontal process and piriform margin or inferior orbital rim. The medial canthi are reattached with *separate* pairs of transnasal wires that are passed through drill holes above and deep to the lacrimal fossa.

Rigid fixation allows realignment of the central upper facial architecture. Although abbreviated plates may be

chosen, the appliance most often extends from the frontal boss to the inferior orbital frame (**Fig. 7.24C**).

Approach to Collateral Damage

Narrowed Nasofrontal Recess

The distal third of the frontal sinus outflow tract (the nasofrontal recess) may be compressed and narrowed by nasomaxillary and/or orbitoethmoid fractures. The frontal sinus *per se* may be spared in these cases, but the nasofrontal transition space may be narrowed and occultly obstructed. Frontal sinusitis and mucopyocele may follow. The time interval between the initial trauma and the development of a mucopyocele in these cases may be “paradoxically” shortened.

Intranasal Obstruction

Inferiorly and posteriorly displaced superior and middle turbinates may contribute to upper nasal vault obstruction, as determined by in-office flexible endoscopy and postoperative



Fig. 7.24 (A–C)

HRCT. Controlled endoscopic-assisted turbinate reduction (using a Stryker [Portage, MI] or Xomed [Medtronic, Inc., Jacksonville, FL] microdébrider) can be quite effective.

Recurrent Dacryocystorhinitis

The lacrimal crests and lacrimal apparatus in the lacrimal fossa may be overtly or covertly damaged by nasomaxillary and/or orbitoethmoid fracture, though the injury may be inapparent in the initial postoperative period. Frequent tearing and/or recurrent dacryocystorhinitis may, however, lead to dacryocystorhinotomy.

Intraorbital Hematoma

Because the anterior and posterior ethmoidal arteries traverse the medial orbital wall at the superior border of the lamina papyracea and may be severed, the nasoethmoid injury may trigger an acute intraorbital hematoma with risk to the viscera and vision. The intraorbital hematoma may also occur on a deferred basis in the immediate postoperative period.

Rhinorrhea

Cerebrospinal fluid leak (rhinorrhea) occurs in 1 to 4% of nasoethmoid fractures, and its presence is confirmed by a positive halo test and β -2 transferin or β -trace protein in the drainage. The drainage abates spontaneously in some two of three cases within 7 days; in the remaining third of patients, the vast majority will respond to intermittent or extended use of a closed lumbar drainage system. Dural tears tend to occur at prior sites of dural attachment near the midline, such as the crista galli, the ala of the cribriform, the orbitoethmoidal roof, or the roof of the sphenoid sinus.^{42–44}

Endoscopic transethmoid insertion of fascia lata at the point of leak(s) is currently favored for those cases requiring surgical intervention, thus avoiding the morbidity of craniotomy or subcranial exposure.⁴⁵ Antibiotics are avoided, for fear of creating resistant organisms, in the absence of compelling evidence of their benefit.

Anosmia/Hyposmia

Anosmia or hyposmia (altered odor detection thresholds to dilutions of pyridine nitrobenzene) have been documented in 8% of patients 1 year after central upper craniomaxillofacial trauma. The incidence rises to 12% in the subset of patients with cerebrospinal fluid rhinorrhea.⁴⁶

Exemplary Repair

Case 10. Nasoethmoid, Zygomatic, Maxillary, and Orbital Fractures

This patient experienced nasofrontal separation and displaced left zygomaticomaxillary and orbital fractures, accompanied by a scalping laceration (**Fig. 7.25A,B**). A Brown-Gruss III compression test elicited proximal collapse and was thus positive (**Fig. 7.25C,D**). The nasal bones are rigidly secured to the repaired anterior table (frontal boss [**Fig. 7.25E**]). The fractures of the left zygoma and maxilla are reduced and stabilized. Note the use of bone grafts (split cranium) across the face of the maxilla, inferior orbital rim, and orbital floor (**Fig. 7.25F–I**). The patient is pictured shortly after surgery (**Fig. 7.25J–N**). The upper central and lower facial architecture was restored. Mild pretraumatic asymmetries persisted (**Fig. 7.25O,P**).

Case 11. Zygomatic Arch, Orbital, Nasal, and Nasoethmoid Fractures

A bullet entered the right preauricular area and traversed the upper central face, creating zygomatic, orbital, nasal, nasomaxillary, and orbitoethmoid pathology. Soft-tissue injury is evident involving the medial canthus and left upper eyelid. The right globe was irreparably damaged (**Fig. 7.26A**). A metal rod was readily passed through the large bullet pathway. Débridement was extensive (**Fig. 7.26B–D**). The right zygomatic arch and the left medial orbital frame were comminuted, creating the orts depicted (**Fig. 7.26E–H**). A bone plate assembly was created, and



Fig. 7.25 (A-F) (Continued)



Fig. 7.25 (continued) (G-P)



Fig. 7.26 (A-F) (Continued)

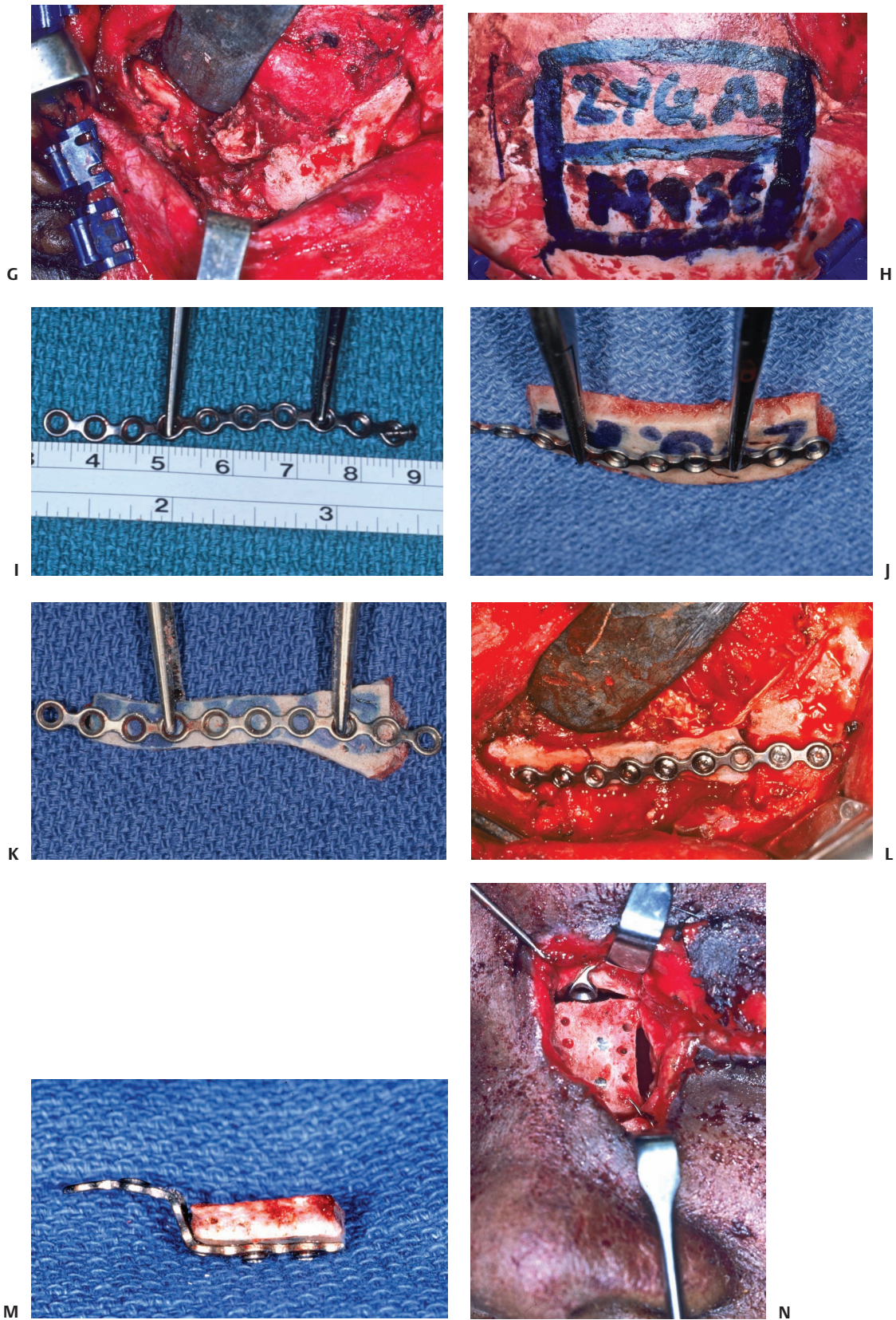


Fig. 7.26 (G-M) (Continued)

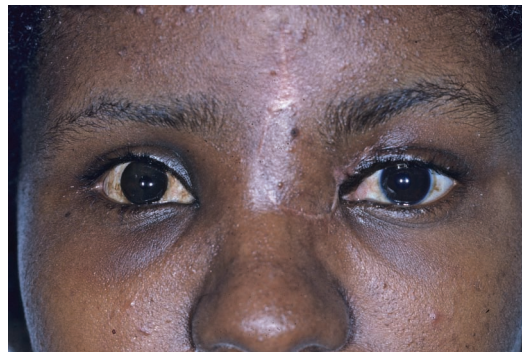
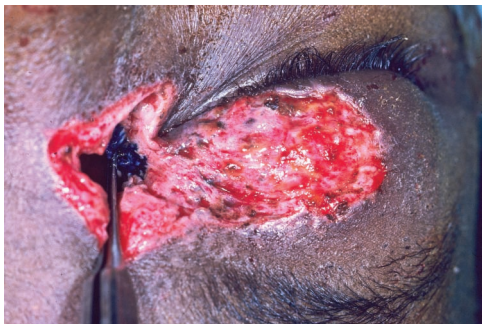
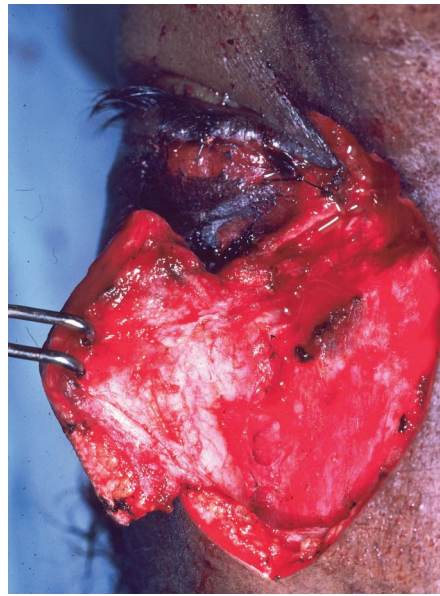


Fig. 7.26 (Continued) (L-T)

the relative linearity of the zygomatic arch was restored (**Fig. 7.26I**). Split cranial bone is pictured after harvest from the outer cortex of the temporoparietal skull (**Fig. 7.26J–L**). A second bone plate assembly was created and applied to in the glabellar region. An advancement rotation flap provided soft-tissue closure (**Fig. 7.26M–R**). An orbital prosthesis in due course completes the restoration, and she is pictured 2 years following surgery (**Fig. 7.26S,T**).

■ Key Points

Nasoseptal, nasomaxillary, orbitoethmoid, and orbitosphenoid fractures disrupt the medial orbital frame and central upper face. A cascade of injury may occur, involving the nasal bones, the nasofrontal processes of the maxilla (the medial maxillary buttresses), the orbitoethmoid buttress, the walls of the ethmoid sinuses, and the rostrum (“face”) and roof of the sphenoid sinus. Damage to the vomer (nasoseptum), located in the midline as a “flying” buttress to support the sphenoid sinus, is common to focused central injury. Displacement of the ethmoid sinus (medial wall of the orbit) contributes to muscle entrapment and often causes expanded orbital volume, a cause of enophthalmos. Fracture of the orbitosphenoid buttress and sphenoid sinus is seen in an increasing cohort of survivors. A major component of the orbitosphenoid buttress, the preannular (posterior) shelf, usually survives high-velocity impact, to then serve as an apical base on which to rest bone grafts and/or commercial implant(s). The posterior maxillary wall, also part of the orbitosphenoid buttress, serves to confirm that the floor implant or graft lies at a proper depth, at the preannular shelf. Loss of vision may accompany traumatic faults in the medial orbital apex; its management has improved using infusions of steroid such that only a small cohort need undergo optic nerve decompression.

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8 The Lateral Orbital Frame, Orbitozygomatic Complex (Lateral Upper Face), and Orbit

With Contributions by M. Douglas Gossman

■ Part 1. Surgical Anatomy and General Considerations

The paired orbits represent a common meeting place of cranial and facial bones. At a key intersection, the orbits protect the eyes and their viscera (the so-called anterior visual systems) and, in the company of adjacent structures, establish upper facial proportion and dimension. As noted in Chapter 1, Cryer considered the zygomatic arch to be a “flying buttress,” supporting the greater wing of the sphenoid, the malar prominence, and temporal bone (**Fig. 8.1A,B**).

The orbits intersect the cranium and face on both a horizontal *and* vertical axis, as depicted in the art form (**Fig. 8.2**).

By way of the nasal bones and the medial orbital frames (frontal processes of the maxillae), the orbits link the central upper face with the lateral upper face, represented by the zygoma, inferior and lateral orbital frame, frontozygomatic (FZ) suture, and the zygomatic arch. In similar fashion, the

superior orbital frame and the roof of the orbit synchronize with the frontal bar and the nasofrontal suture. The orbits vertically align with the palate and maxillomandibular block below and the sphenoidal platform above by way of the anterior and posterior maxillary buttresses, respectively.

The General Architecture of the Orbit

The shape of the orbit can be likened to a pear or an Erlenmeyer flask, particularly in late adolescence and adulthood. The body of the flask or fruit is seated in the bilge of the floor and bilge of the roof (**Fig. 8.3A**).

The neck tapers toward the apex and the stem tilts upward, because the optic canal is at a higher level than the inferior orbital rim (**Fig. 8.3B**).

Contrary to common perception, the orbit is not triangulated, *except* at the apex. A model pine tree or triangulated Lego® (Billund, Denmark) construct, for example, is comparatively *ill*-fitting, except in the apex of the orbit (**Fig. 8.4A–C**).

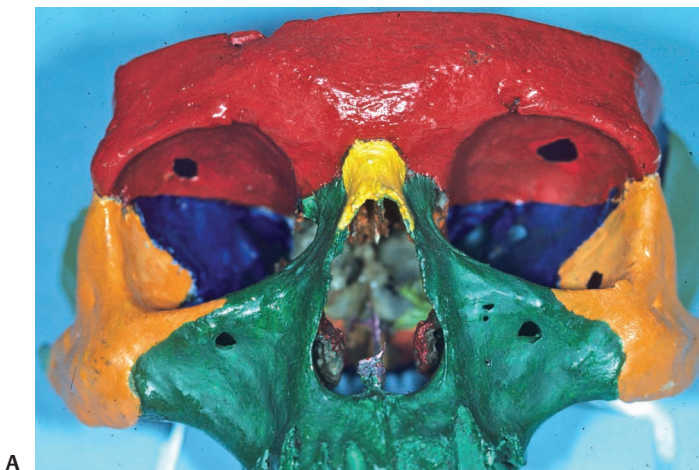


Fig. 8.1 (A, B)

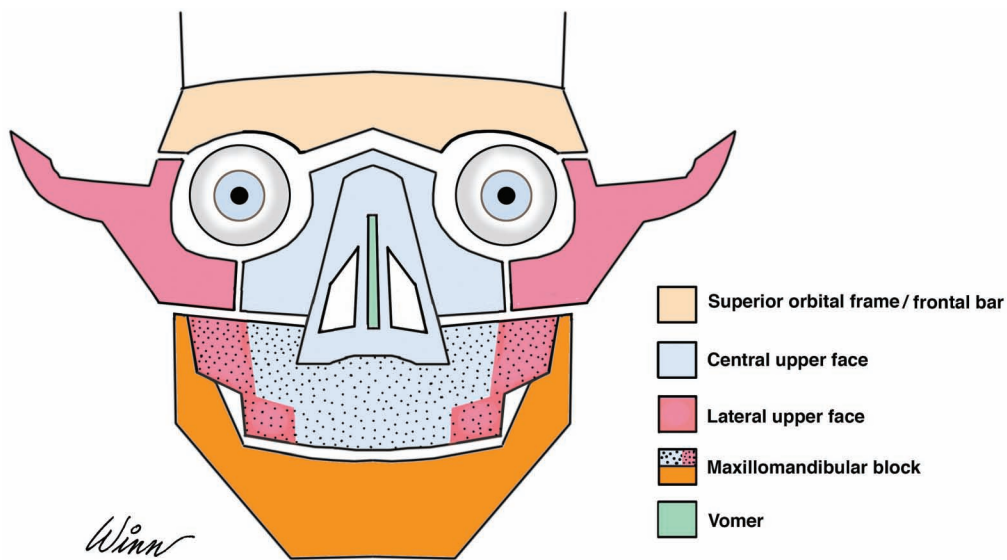


Fig. 8.2

Orbital Osteology

Each of seven bones contributes to the orbit. The contributions are most evident in painted skulls, as the *frontal*, *sphenoid*, *ethmoid*, *lacrimal*, *maxilla*, *palatine*, and *zygoma* bones.¹⁻⁴ An acronym to remember the seven bones is “funky Susie Elberton likes munching pretzels at the zoo.” The palatine bone’s contribution is easily forgotten, so we have reminded students, residents, and fellows

in training that they had “best remember the pretzels!” (Fig. 8.5).

The temporal bone is only distantly involved, to the extent that it provides a zygomatic process to complete the zygomatic arch. The occipital bones offer no contribution to orbital structure.

Tessier and coauthors emphasize, as would we, that “orbital bones” (strictly speaking) “do not exist but, rather, are contributions made by bones of the cranial and facial skeleton.”¹

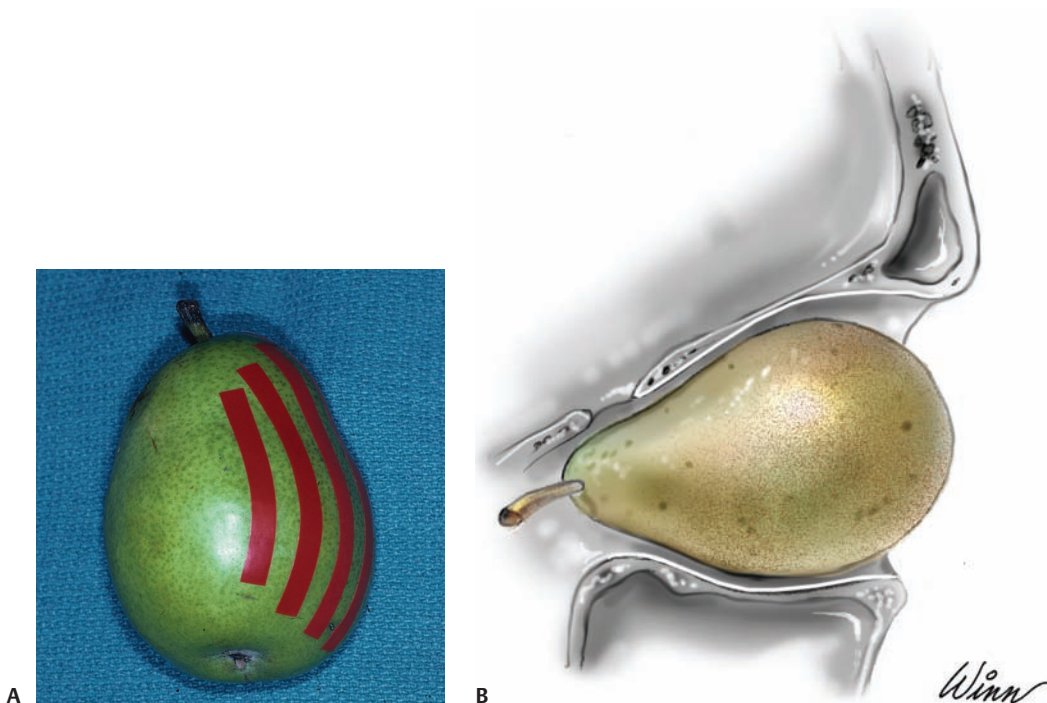


Fig. 8.3 (A, B)

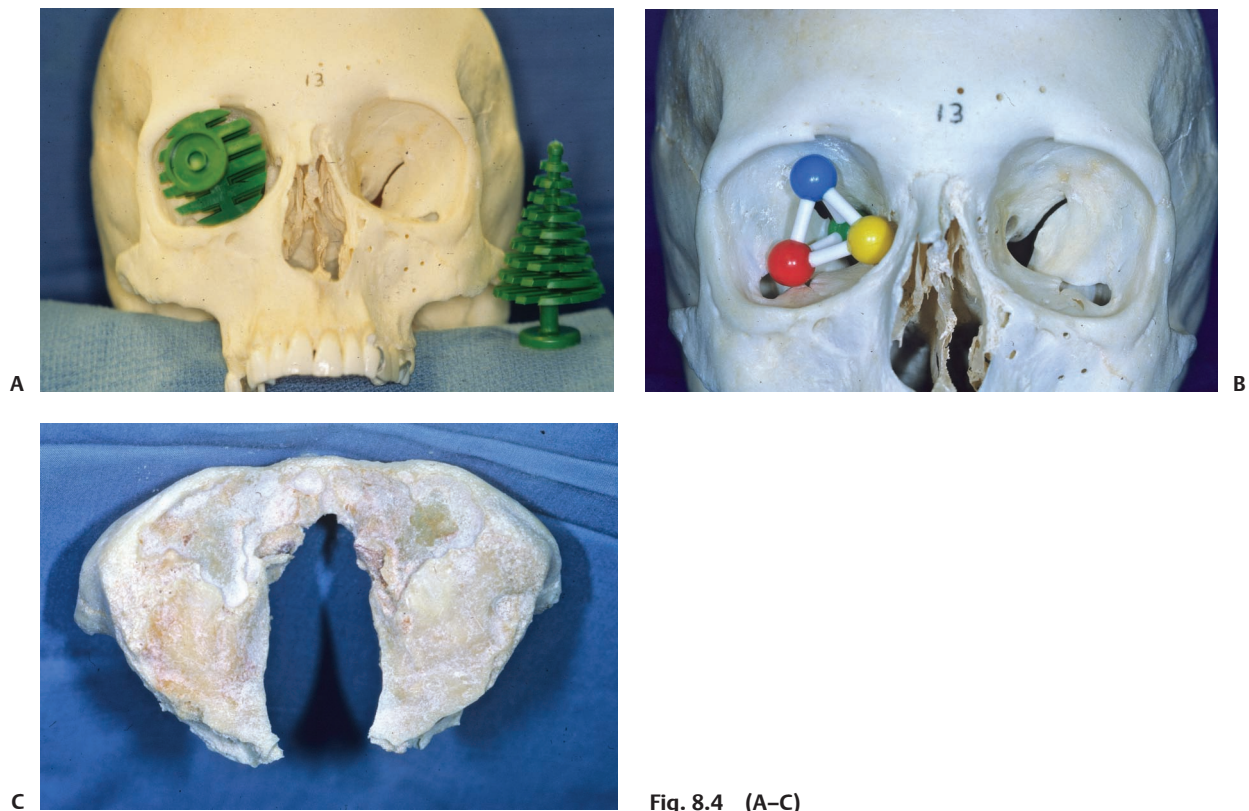


Fig. 8.4 (A-C)

The Orbital Roof

The *frontal bone* forms the anterior orbital roof, and the *sphenoid bone* forms the posterior orbital roof, as vividly depicted by painted skulls (Fig. 8.6A-C).

The posterior medial portion of the orbital roof adjacent to the outlet of the optic canal is thin and prone to fracture, as most evident in the illuminated skull and three-dimensional reformats.

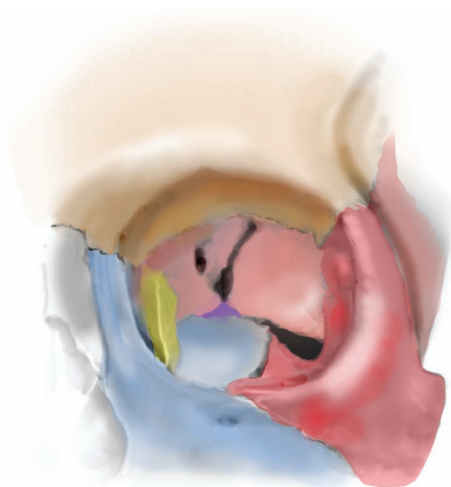


Fig. 8.5

Medial fractures may reach the floor and posterior table of the frontal sinus.⁵ Load forces concentrated in the more rigid bone of the posterior lateral portion of the orbital roof may reach the optic canal or extend to the anterior cranial vault or middle fossa.

The Medial Orbital Wall

The lamina papyracea of the *ethmoid bone* forms the medial orbital wall and anteriorly joins the *lacrimal bone* and maxillary process of the *frontal bone*, creating the posterior lacrimal crest. The middle and posterior ethmoid cells project *into* the orbit, subtly reducing the posterior orbital volume. Known as the *ethmoid jut*,^{6,7} the degree of curvature varies among individuals and is challenging to reconstruct; the convexity of temporoparietal split cranial bone best matches the jut when a bone graft is used. The medial wall gains only modest strength from the cross-struts ("septa") within the middle and posterior ethmoid sinuses. The *ethmoid jut* is notably apparent when the orbital roof has been drilled away, providing a glimpse of the reduced orbital volume caused by its inward contour (Fig. 8.7A,B).

The anterior and posterior ethmoidal foramina, visible landmarks that define the boundary between the medial wall and roof (the frontoethmoid suture) of the orbit, lie in line with each other, some 25 and 35 mm, respectively, from the anterior lacrimal crest. They serve as guides to

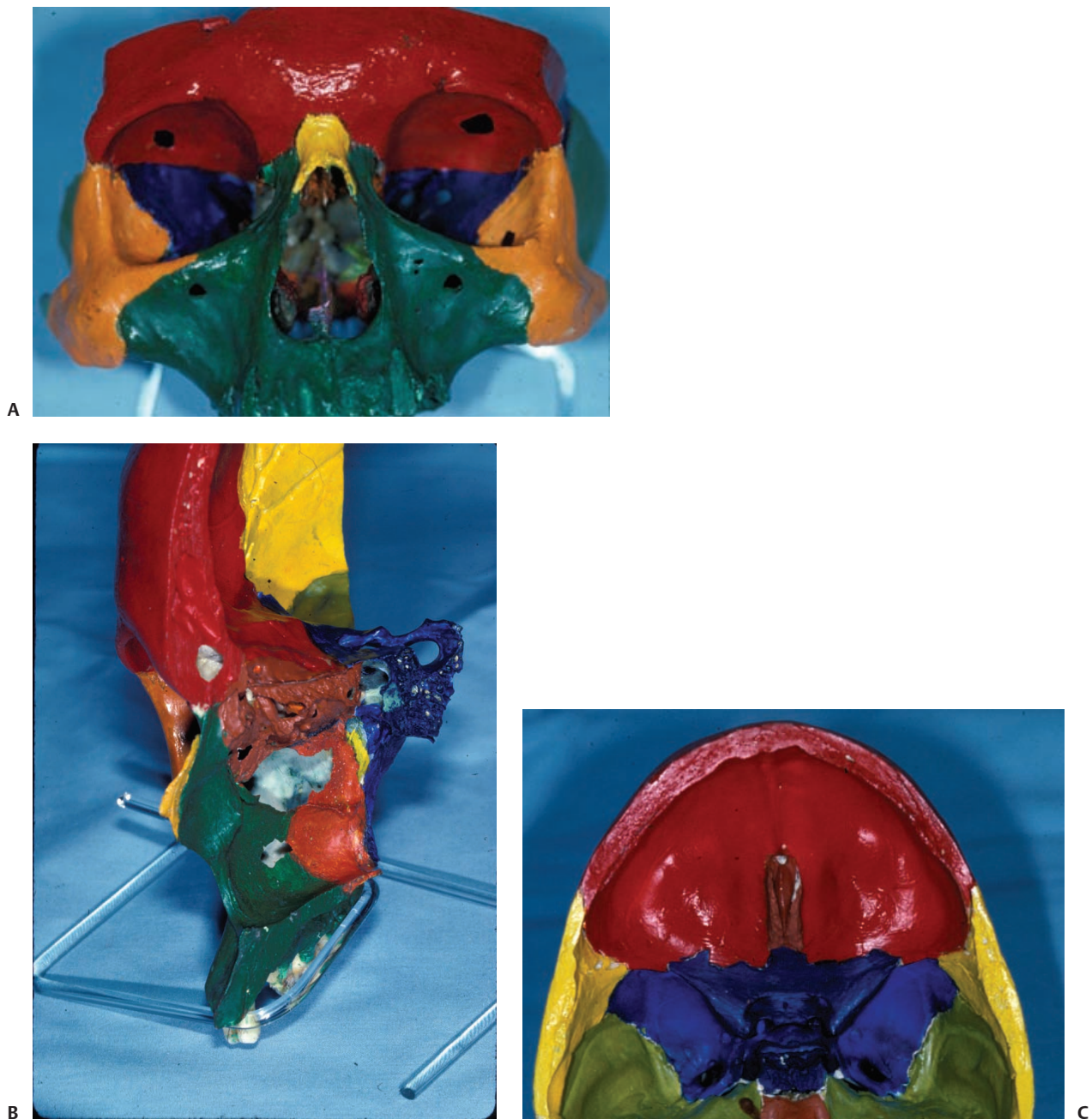


Fig. 8.6 (A–C)

the location of the outlet of the optic canal, some 10 to 15 mm further inward. The ethmoid foramina are not found at the most superior portion of the orbit but are located at the level of the cribriform plate (Fig. 8.8).

The Lateral Orbital Wall and the Orbitozygomatic Complex

The lateral wall of the orbit posteriorly is formed by the *greater wing of the sphenoid* and anteriorly by the *orbital plate of the zygoma* (Fig. 8.9A,B).

The two components of the lateral wall lie on a straight line directed toward the *optic strut*, the pillar-like column of bone immediately inferolateral to the optic foramen.^{4,6,7} The *optic strut* is part of the lesser wing of the sphenoid, lies at a 45-degree angle, and is strategically located to buttress the inferolateral aspect of the optic canal and superomedial aspect of the superior orbital fissure (Fig. 8.10A,B).

The greater wing of the sphenoid is curvilinear as the roof is engaged above and as the inferior orbital fissure is reached below. Reestablishment of the camber of the wing (*sphenoid*

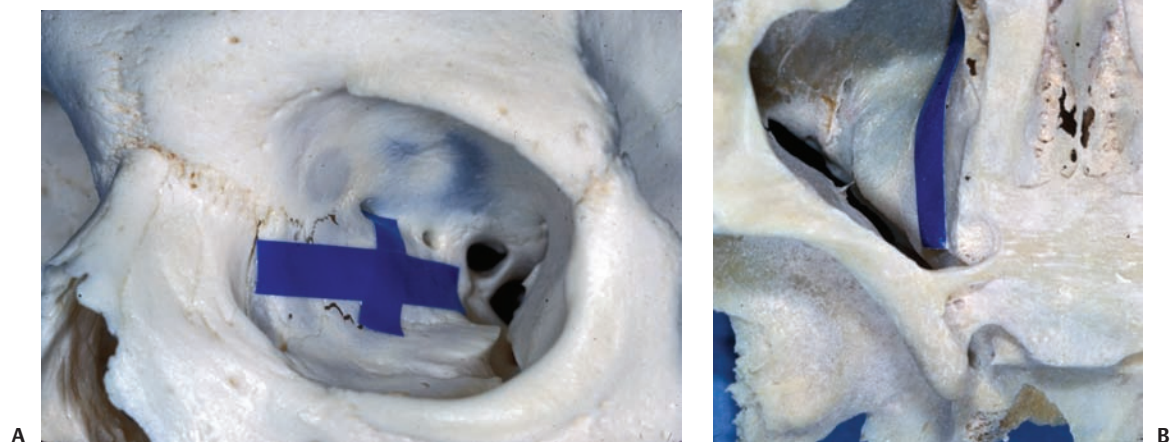


Fig. 8.7 (A, B)

cant)^{4,6,7} is critical to ensure proper positioning of the fractured zygoma and to restore orbital volume (Fig. 8.11).

The smooth continuity of the two components of the lateral wall is readily recognized when the orbital roof has been drilled away with cutting burrs (Fig. 8.12).

Note the proximity of the middle fossa (and tip of the temporal lobe) deep to the greater wing of the sphenoid.

The body of the zygoma (orbitozygomatic complex) is underpinned by a lower process (the *anterolateral midfacial buttress*) arising from the thickened periphery

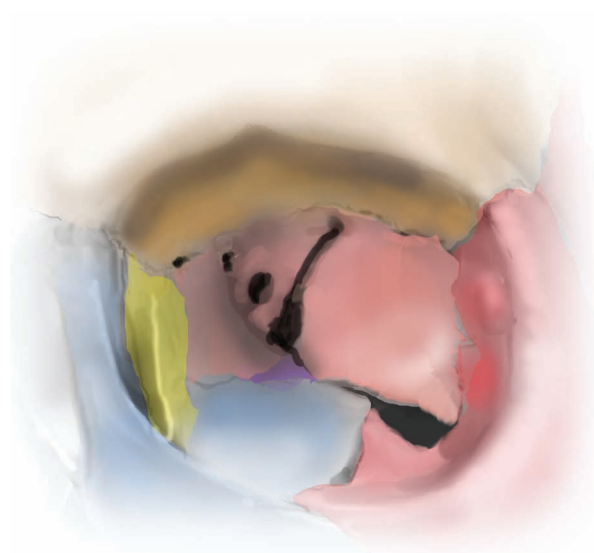


Fig. 8.8



A



B

Fig. 8.9 (A, B)

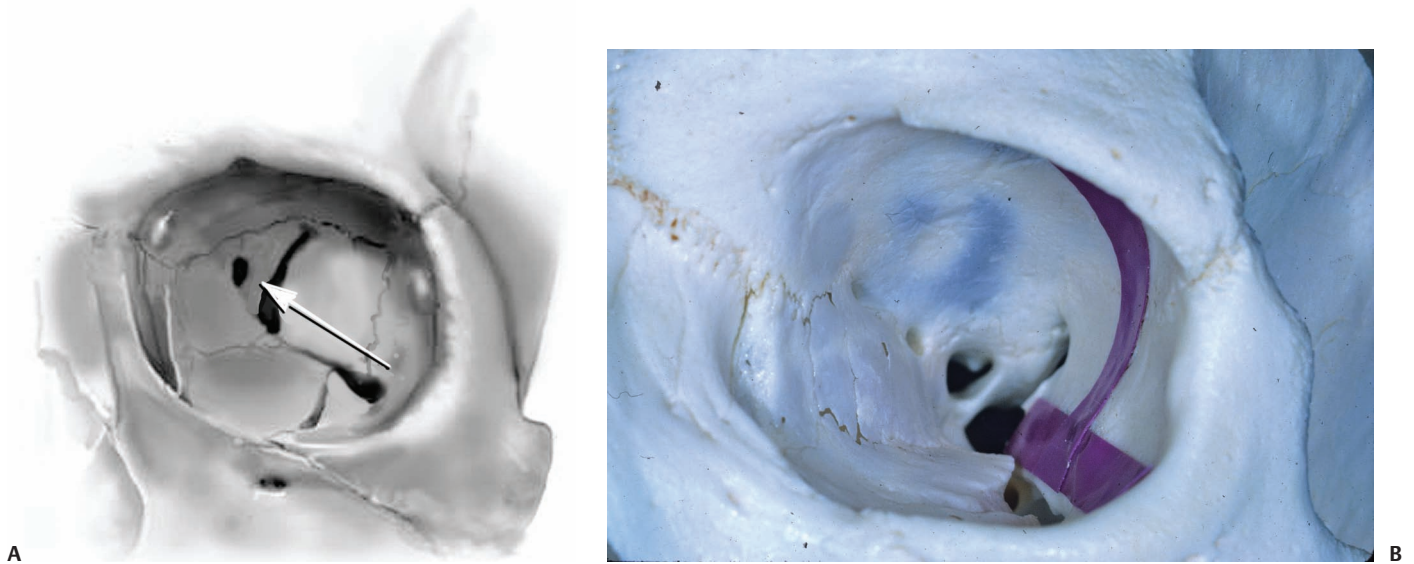


Fig. 8.10 (A, B)

(alveolar process) of the palate (see Chapter 4). From the malar prominence arise four additional processes that are key to preoperative assessment and to operative finesse (Fig. 8.13):

1. The *frontal process of the zygoma* leaves the malar prominence and joins the zygomatic process of the frontal bone at the FZ suture, as noted previously.
2. The *inferior orbital process* reaches medially, creating the lateral shape and contour of the inferior orbital rim. It ends at the infraorbital foramen.
3. The *orbital plate of the zygoma* that engages the greater wing of the sphenoid.

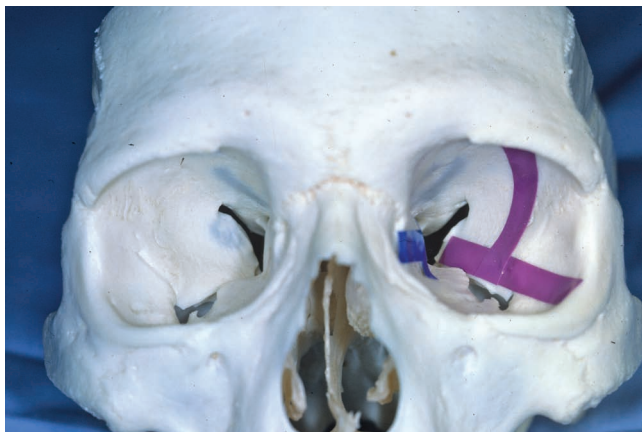


Fig. 8.11

4. A *temporal process* leaves the zygomatic body to unite with the zygomatic process of the temporal bone. This combined span is referred to as the zygomatic arch. Their serrated intersection at midarch is called the zygomaticotemporal suture.

The zygomatic arch has a relatively flattened midsection, the length and linearity of which determines the projection of the body (malar prominence) of the zygoma. The arch is similar to the third (bottom) of three kitchen drawer pulls depicted (Fig. 8.14).

The zygomatic arch is an important reference point in reestablishing correct anterior projection of the cheek during fracture repair. It is often manipulated from below with an instrument in one hand, and the linearity at the midaspect of the arch enforced by applying external, digital pressure over the arch with the other hand.⁸ This “trimanual” manipulation is similar to the “bimanual” reduction of a large nasal fragment by Manson.⁹ A coronal incision is required for more complex, unstable fractures of the arch; the linear architecture of the zygomatic arch is then readily reestablished with rigid fixation devices.

The Orbital Floor

Constituents of the maxilla and zygoma that make up the inferior orbital rim also contribute to the floor of the orbit. The floor initially descends from the rim, forming a “bilge” (the greatest internal diameter of the orbit), some 1.5 cm



Fig. 8.12

behind the rim. The floor then gradually ascends to the apex, canting upward toward the ethmoid to lie in a plane that is above the orbital rim. Reconstitution of these contours favors proper restoration of orbital volume during reconstruction (**Fig. 8.15A–C**).

Transillumination demonstrates the thinness of the orbital plates of the maxilla and inferior ethmoid.¹⁰

The area of greatest attenuation lies *medial* to the infraorbital canal and is the primary locus of disruption when load forces are applied to the inferior orbital rim.



Fig. 8.13

The relatively thicker lateral floor resists fracture, and the medial constituent often breaks parallel to the infraorbital canal, creating a hinged fragment (a so-called trap door) at its union with the ethmoid bone. The more vertical portion of the ethmoid plate may fracture concurrently.

The roof of the maxillary sinus and a small contribution of the palatine bone (see Chapter 4) create the *preannular* (posterior) *shelf* of the posterior orbital floor, some 25 mm from the inferior orbital rim.^{4,6,7} The shelf is a horizontal microbuttress of the orbit, just anterior to the *infraorbital tubercle* (that provides the site for insertion of the *annulus of Zinn*). The cresting of the bilge creates the recognized “post-bulbar constriction” behind the globe.^{2,3} The size and definition of the *preannular shelf* varies from person to person but in general is larger in men and smaller in women. It is large and plateaued in some, but petite and ledge-like in others. High-resolution computed tomography (HRCT) helps delineate this anatomical variance prior to surgery (**Fig. 8.16**) as part of the orbitosphenoid buttress.

As pictured in the preceding skull and **Fig. 8.17**, the preannular shelf is below the level of the superior orbital fissure, the optic strut, and the outlet of the optic canal, yet in turn is above the level of the inferior orbital rim.

The ascent of the posterior orbital floor to reach the preannular shelf is restored in cases with posterior orbital “blow-out fracture.” The *preannular shelf* provides a platform or horizontal microbuttress upon which to rest commercially available polyethylene implants or bone grafts.^{4,6} Stability of the commercial implant is aided by embedded alloy mesh, similar to that intrinsic to split bone harvested from the temporoparietal skull. If the shelf is missing (an unusual but possible circumstance, usually in women), the posterior wall of the maxillary sinus, medial to the neurovascular bundle, usually suffices. The split cranial graft or premanufactured implant is secured to the orbital frame with a plate and screws.

A *vertical line* dropped from the common wall shared by the posterior ethmoid and sphenoid sinuses approximates the *anterior boundary of the middle cranial fossa* above and the *orbitosphenoid buttress* below. The line thus passes



Fig. 8.14

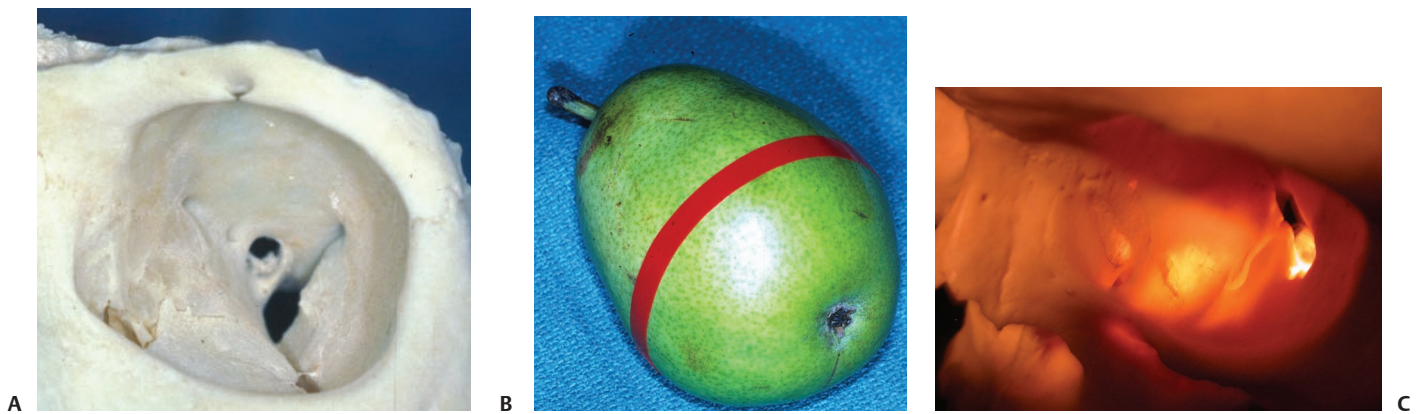


Fig. 8.15 (A–C)

inferiorly through the lesser wing of the sphenoid medial to the outlet of the optic foramen, the preannular (palatine) shelf of the posterior orbit, and the posterior wall of the maxillary sinus. As such, it also identifies the *anterior boundary of the infratemporal fossa* (Fig. 8.18).

Trisectional Architecture of the Orbit

According to Dupuytren and colleagues^{11,12} and, after him, Desmarres,¹³ Lagrange,¹⁴ Tessier and colleagues,¹ Manson,⁹ and Gossman and Pollock,⁴ the orbit is conveniently divided into three sections:

1. The orbital frame
2. A midsection
3. The orbital apex^{1,4,9,11–14}

This arbitrary trisection, we have found, has value during radiographic assessment, preoperative planning, and operative repair. The trisection of the orbit is also useful in anatomical and reconstructive descriptions, as the anatomy of each section has recordable structural differences (Fig. 8.19A).



Fig. 8.16

The Orbital Frame (Orbital Rim)

The spiral-like external rim (orbital frame) (Fig. 8.19B) is made up of three separate bones, creating three components such that there are *superior*, *medial*, and *inferolateral* sections, as described by Tessier and colleagues¹ and by Manson⁹ (Fig. 8.20):

1. The superior (supraorbital) section extends, as part of the frontal bar, from the frontonasal suture to the FZ suture.
2. The medial orbital frame descends from the frontonasal suture and curves laterally to end at the zygomatico-maxillary suture of the inferior orbital rim; it is derived from the terminal ascent of the frontal process of the maxilla.
3. The inferolateral section of the inferior orbital frame is formed by the zygomatic bone.

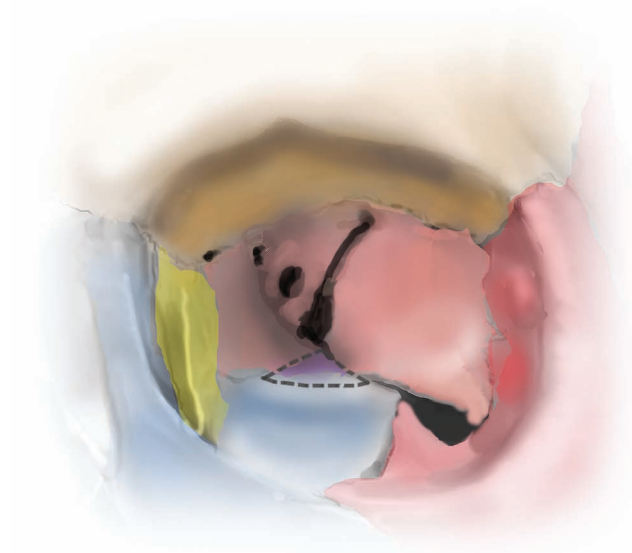


Fig. 8.17

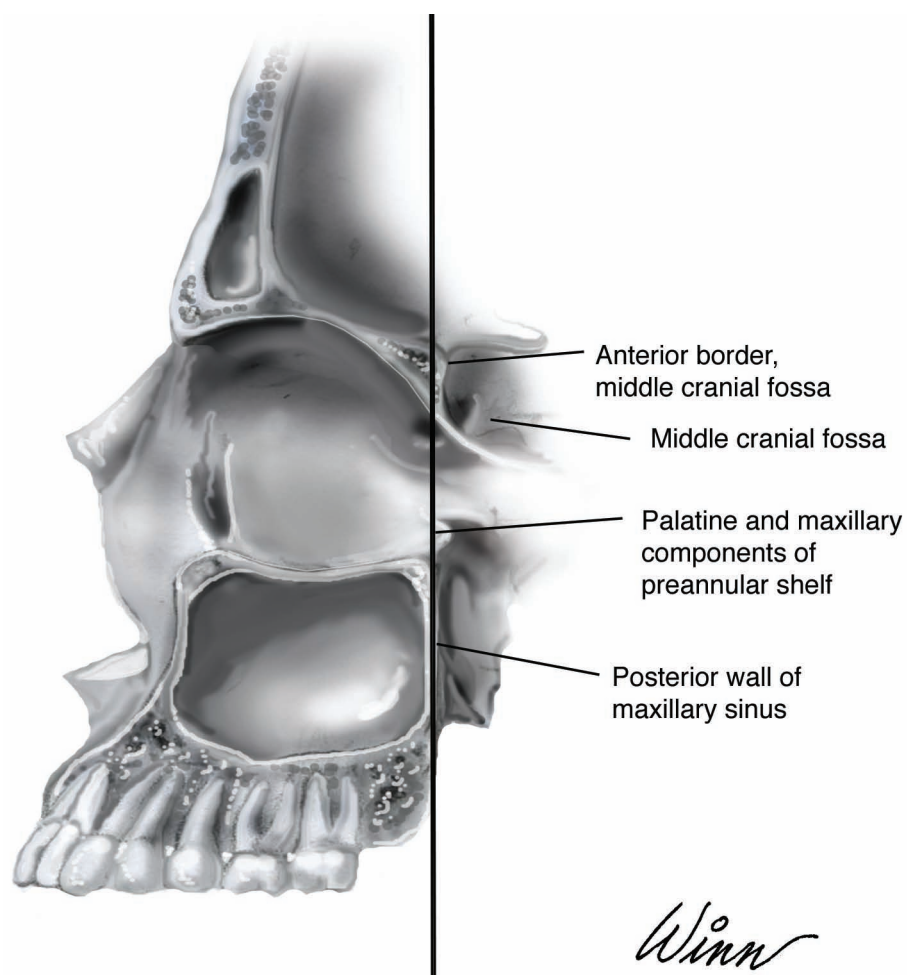
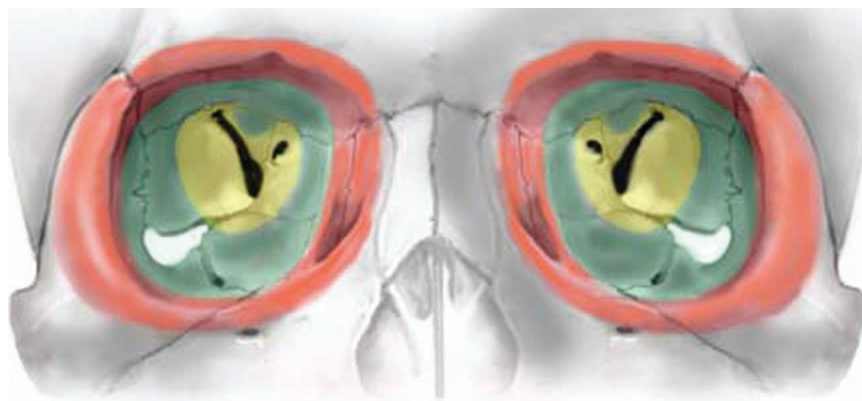


Fig. 8.18

Three foramina perforate the orbital frame, somewhat weakening its osseous structure. The foramina are in the main vertically aligned. The *supraorbital foramen* (or *supraorbital notch*, in 15% of cases) perforates the supraorbital section on the midpupillary line.

The *infraorbital foramen* perforates the zygomatic section some 8 mm below the margin, on the midpupillary line. The *zygomaticofacial foramen* also exits the zygomatic section approximately 8 mm below the rim.³ Fractures at or near these weakened sites are common.^{2,4,9}



A



B

Fig. 8.19 (A, B)

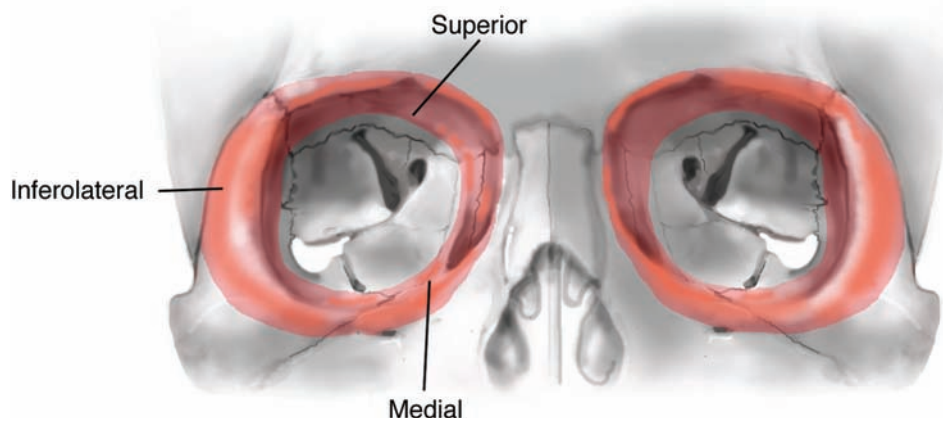


Fig. 8.20

A vertical line descending from the supraorbital and infraorbital foramina intersects the pupil, a bicuspid, and the mental foramen of the mandible (**Fig. 8.21**).

Each section of the orbital frame harbors an anatomical landmark. A key landmark of the supraorbital section, as it turns toward the supraorbital notch, is the *trochlear spur*.^{2,3} It serves to anchor the cartilaginous pulley of the superior oblique muscle. Landmarks of the medial section include the anterior lacrimal crest of the maxilla and the posterior

lacrimal crest (of the lacrimal and ethmoid bones). The former is a point of attachment for the anterior medial canthal tendon and orbicularis muscle. Three entities attach to the posterior crest: Horner's muscle, the medial horn of the levator palpebrae superioris, and the medial attachment of Lockwood suspensory ligament.^{2,3,15} The anterior canthal tendon serves primarily as a check ligament.

A key landmark of the inferolateral (zygomatic) component is *Whitnall's tubercle*,²⁻⁴ residing some 10 mm below the FZ suture and 4 to 5 mm inside the lateral orbital rim. The tubercle is the site of four attachments of the lateral canthal complex, including the lateral canthal tendon, the lateral horn (extension) of the levator aponeurosis, the lateral attachment of Lockwood's suspensory ligament, and a check ligament of the lateral rectus muscle (**Fig. 8.22**).

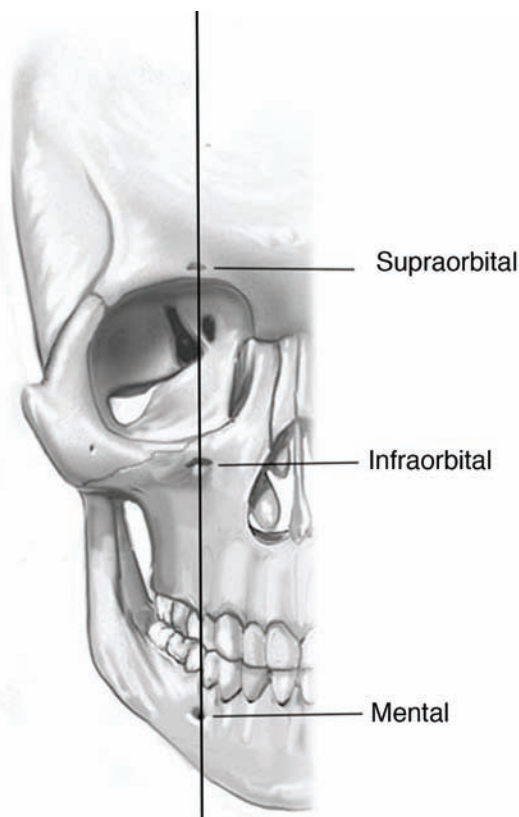


Fig. 8.21

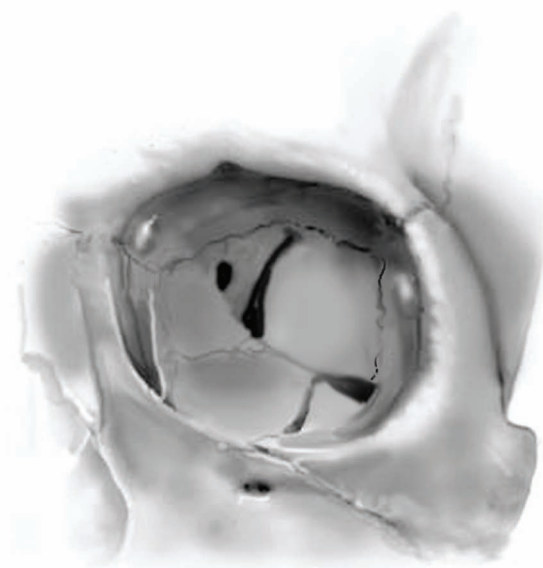


Fig. 8.22



Fig. 8.23

The Orbital Midsection

The bone of the middle third of the orbit is thin and is composed of four sections (the roof, medial wall, lateral wall, and floor), as described by Dupuytren, Desmares, Manson, and Gossman. The restoration of each section is important as one of the more accurate guides to volume restoration of the orbit at surgery^{4,6,7,9,16} (Fig. 8.23).

The medial and lateral orbital walls high up are initially flush with the orbital margin. The curvilinear nature of the medial wall is maintained over most of its course, until the posterior ethmoidal foramen is reached. Thereafter, the medial wall turns crisply toward the *outlet of the optic canal*, the *optic strut*, and the *superior orbital fissure* (Fig. 8.24).

The lateral wall angles almost immediately toward the apex of the orbit^{2,3,17} in the direction of the superior orbital fissure and optic strut. The lateral wall crosses the imaginary sagittal centerline of the orbit at the anterior ethmoidal foramen in the coronal plane.⁴

The floor and the roof of the orbit immediately cant away from their respective rims and the center of the orbit, creating recesses that are more prominent laterally (the orbital “bilge”).²⁻⁴ The floor reaches its maximum descent some 1.5 cm behind the inferior orbital rim. The ensuing ascent is slightly steeper over its medial aspect. This difference in the rate of rise (between the medial and lateral floor) imparts a cant to the medial and lateral floor. The floor separates the orbit from the maxillary sinus.

Cross-sections of a colloid impression of the left orbit at intervals of 0.5 cm demonstrate the cant of the floor and the change in cross-sectional area from frame to apex¹⁰ (Fig. 8.25).

To avoid post-traumatic enophthalmos, the contoured bilge and ascent of the floor are reconstructed at surgery. When restoring the orbital floor, the surgeon is well served recognizing that the orbital floor is the shortest of the four orbital surfaces. Generally, as emphasized by Converse and colleagues^{18,19} and by Manson,⁹ floor fractures first involve the floor medial to the infraorbital

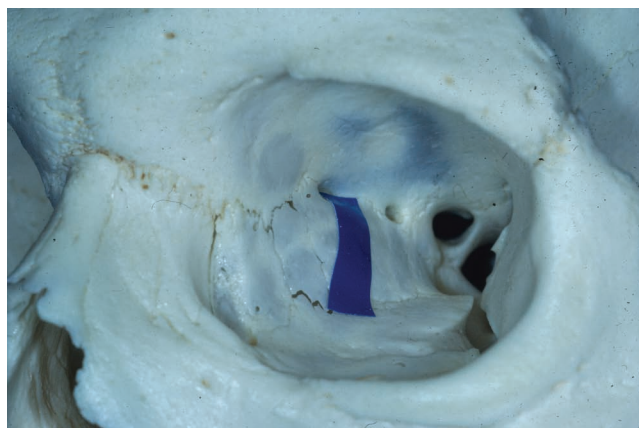


Fig. 8.24

groove but often then extend to concomitantly involve the lower portion of the medial orbital wall. The *infraorbital groove* is an important reference structure that, in addition to housing the infraorbital nerve and its vasculature, marks the transition from the thicker lateral orbital plate to its more delicate medial counterpart.^{3,4} Lateral to the *infraorbital groove*, the maxilla and the orbital plate of the zygoma, for example, typically measure more than 1.0 mm in thickness; the medial floor by comparison is approximately 0.5 mm thick.

The Orbital Apex

The deepest trisection of the orbit is triangulated, as seen in prior art, and constructed of thicker bone.⁶⁻⁸ Incorporated in the apex are the *outlet of the optic canal* (colloquially

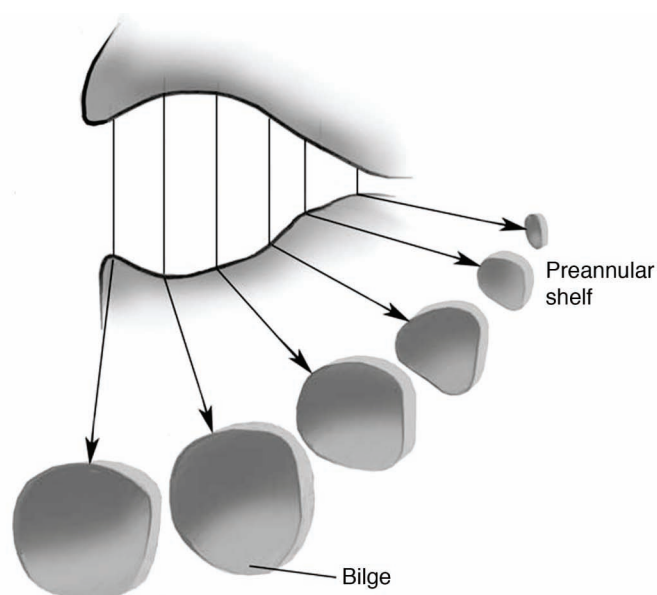


Fig. 8.25

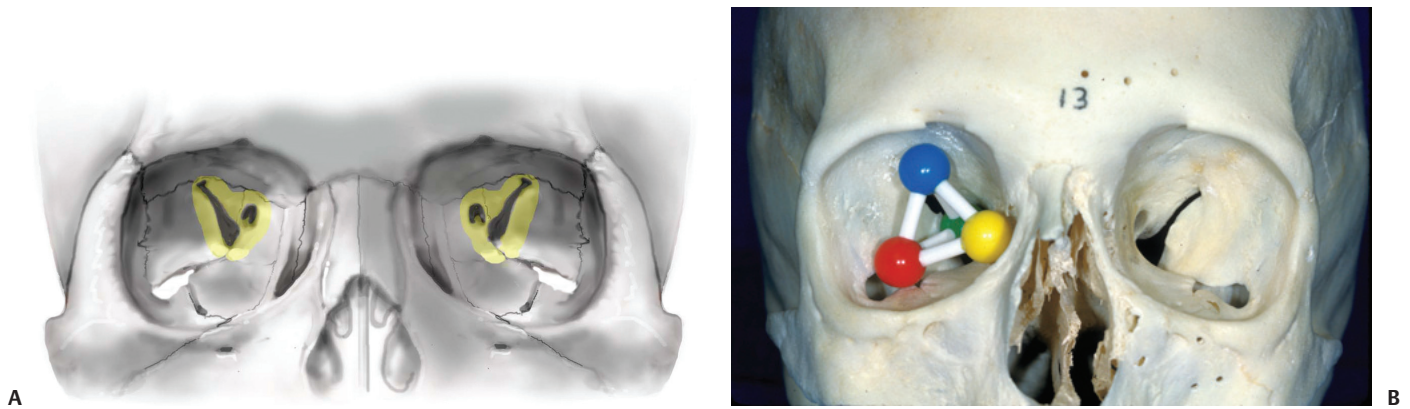


Fig. 8.26 (A, B)

called the “optic foramen”) and the *superior* and *inferior orbital fissures*. The outlet of the optic canal is protected by the roots of the lesser wing of the sphenoid, including the *optic strut*,⁶ the pillar separating it from the superior orbital fissure (**Fig. 8.26A,B**).

The preannular shelf (palatine), the cross-struts (septa) of the middle and posterior ethmoid sinuses, the thick orbital plate of the frontal bone, the lesser wing of the sphenoid, the optic canal, the optic strut, and greater wing of the sphenoid act as *microbuttresses* to “ring” the apex of the orbit. The thicker character of the bone about the orbital apex is evident by photography, particularly by backlighting (**Fig. 8.27A,B**).

The optic canal allows the passage of the optic nerve and the ophthalmic artery. Through the superior fissure pass *cranial nerves III, IV, and VI* and the ophthalmic division of *trigeminal nerve (V-1)*.

The *inferior orbital fissure* separates the orbital floor from the lateral orbital wall. The infraorbital nerve (en route to the infraorbital foramen), the zygomaticofacial nerve, and the infraorbital artery pass through the fissure posteriorly. The fissure further anteriorly is occupied by ligamentous structure, orbital fat, and veins.²

The outlet of the optic canal is at a higher plane than the inferior orbital rim and the preannular shelf, such that the optic nerve is relatively protected during dissection to expose the preannular shelf (**Fig. 8.28**). Split cranial bone grafts or commercial implants rest on the preannular (posterior) shelf but are secured with screws only to the inferior orbital rim (**Fig. 8.28**).

The frontal bone's contribution to the orbital roof has been drilled away in this specimen for lighted exposure of the preannular shelf and the apex.

The *optic canal* measures approximately 5 mm in diameter and 10 mm in length. Progressively and inwardly, it changes from a near-circular shape at the canal outlet, to a circle at its midsection, and to a lenticular shape at the cranial inlet^{20–22} (**Fig. 8.29**).

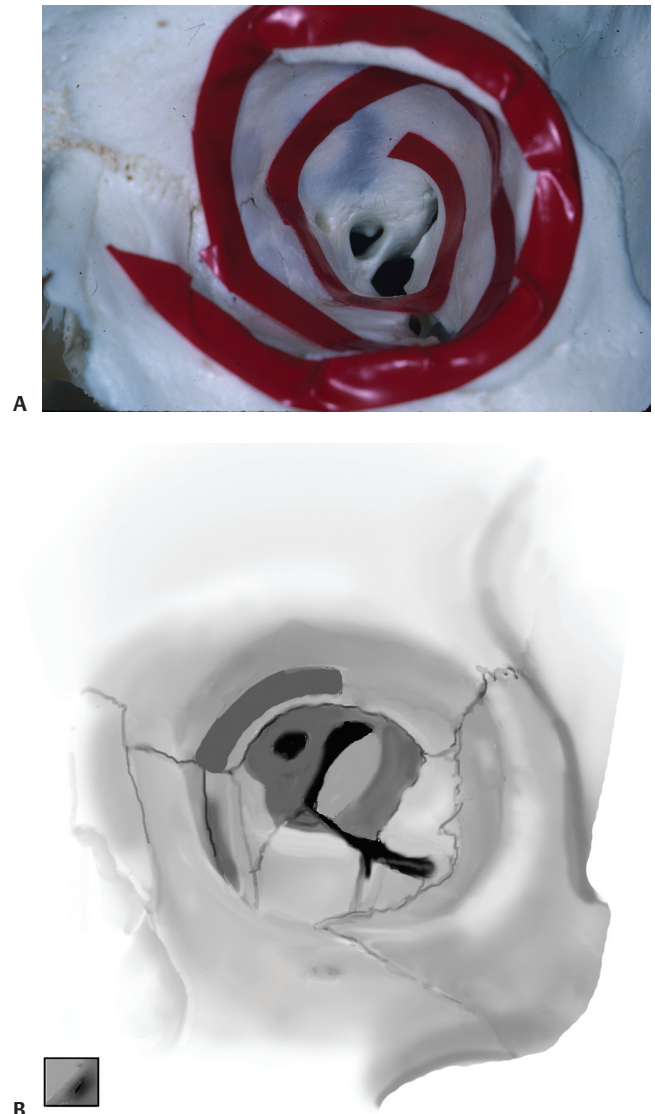


Fig. 8.27 (A, B)



Fig. 8.28

The roof (*anterior clinoid*) and lateral wall of the optic canal are relatively strong (in part because of the *optic strut*) but are occasionally pneumatized. The inferomedial wall of the optic canal has variable thickness and breadth and separates the canal from the posterior ethmoidal

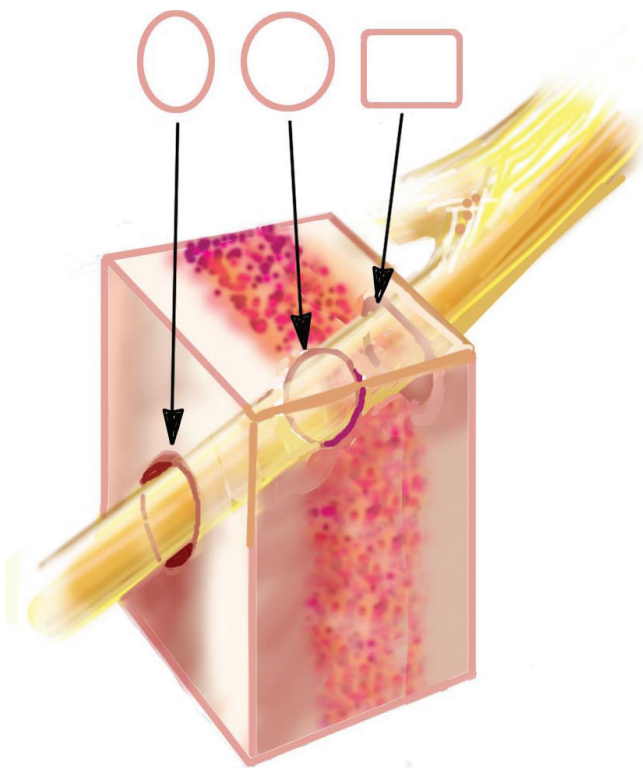


Fig. 8.29

cells. The cross-struts (“septa”) within the posterior ethmoid cells are substantial and add to the strength of the posterior medial wall and the orbital apex, as noted previously.

The floor of the optic canal separates the optic nerve from the *internal carotid artery*. The vertical opening of the adjacent *superior orbital fissure* measures 15 or so mm and is a potential portal of entry to the middle cranial fossa and *cavernous sinus* from the orbit.²¹

■ Part 2. Operative Technique and Exemplary Repair

For several decades, operative repair of the orbit created controversy. Fortunately in recent years, the anatomy of the orbit and indications and approaches to orbital trauma repair have been elegantly delineated.^{4,8,9,23–41} The orbital trauma surgeon is particularly indebted to Tessier¹ and Gerard Guiot and numerous other surgeons and anatomists, such as Whitnall² and Zide.³ Their collective contributions produced operative paradigms that changed the way orbital repair after trauma has been effected.

About half of all orbital fractures involve the *orbital frame*, and the injury is then relatively extensive. In the other half, the injury is more isolated in the contoured, thin-boned *midsection* of the orbit. Management naturally differs in the two groups and their subsets. The bone of the *orbital apex* is seldom directly involved in populations of surviving patients. Rather, apical injury is most often noted in the nonsurviving cohort. Components of the orbital frame or orbital walls may collapse in isolation or in combination, creating unique functional disorders.

Satisfactory outcomes are a direct function of timely analysis and accurate clinical evaluation. Repeat examination of injuries of the periorbital region is commonplace, as initial intraorbital and periorbital swelling abates and HRCT is completed. A systematic approach on each examination increases the likelihood that subtle injuries will be recognized.⁴²

Preoperative Assessment and Indications for Repair

Clinical Presentation

Initial ocular evaluation in the setting of periorbital fractures seeks to determine the status of pretraumatic vision and prior intraocular surgery, the functional and anatomic status of the eyelids and pupils, the quality of the anterior and posterior segments of the eyes, the

state of ocular motility, and the current state of visual acuity. Armed with this information, the surgeon is able to declare (or not declare) the need for ophthalmologic evaluation.

Basic assessment is best achieved in six steps, avoiding meaningless generalities such as “examination grossly normal” or “pupils equal, round, reactive to light and accommodation,” as follows:

1. Status of the eyelids (assessing the external and conjunctival surfaces)
2. Size and shape of the pupils; reaction of the pupils to bright light, particularly the presence or absence of the afferent pupillary defect; and direct pupillary response to alternating light, as it passes briskly between the two eyes
3. Clarity of the cornea and anterior chambers, attempting to ferret out asymmetries, corneal laceration, hemorrhage, globe rupture, and hyphema
4. Ophthalmoscopic presence of a red reflex, macula, and optic nerve-head and absence of enfolding of the outer layer of the retina (*commotio retinae*)
5. Complete range of motion in both vertical and horizontal gaze
6. Distant and near vision, with one eye occluded (if vision is so challenged that fine print cannot be read, the ability to count fingers should be noted)^{43–46}

Abnormalities in *any* of the six-point assessment merit ophthalmologic consultation.

Radiographic Assessment of Orbitozygomatic Fractures

The zygomatic fracture can be classified into three patterns of presentation (**Fig. 8.30A,B**):

1. Medialward rotation, displacing the zygoma inward, downward, and posteriorly
2. Lateralward rotation, displacing the zygoma downward, outward, and posteriorly
3. Posterior displacement, with minimal rotation, similar to modest, inward displacement of a “swinging gate”

The pivot point of rotation is at the FZ suture, and the degree of rotation is largely dependent on the status (comminution) of the zygomatic arch and (the displacement of) the orbital plate of the zygoma. *The relationship of the zygoma with the sphenoid (greater wing) and with the temporal bones (zygomatic process of the temporal bone) is key to gauging the degree of displacement; that same relationship is germane to anatomical repair of the fractured bone.*

HRCT and three-dimensional reformats usually confirm the clinical examination, including step-offs at the inferior orbital rim and FZ suture. Although overprojection of the

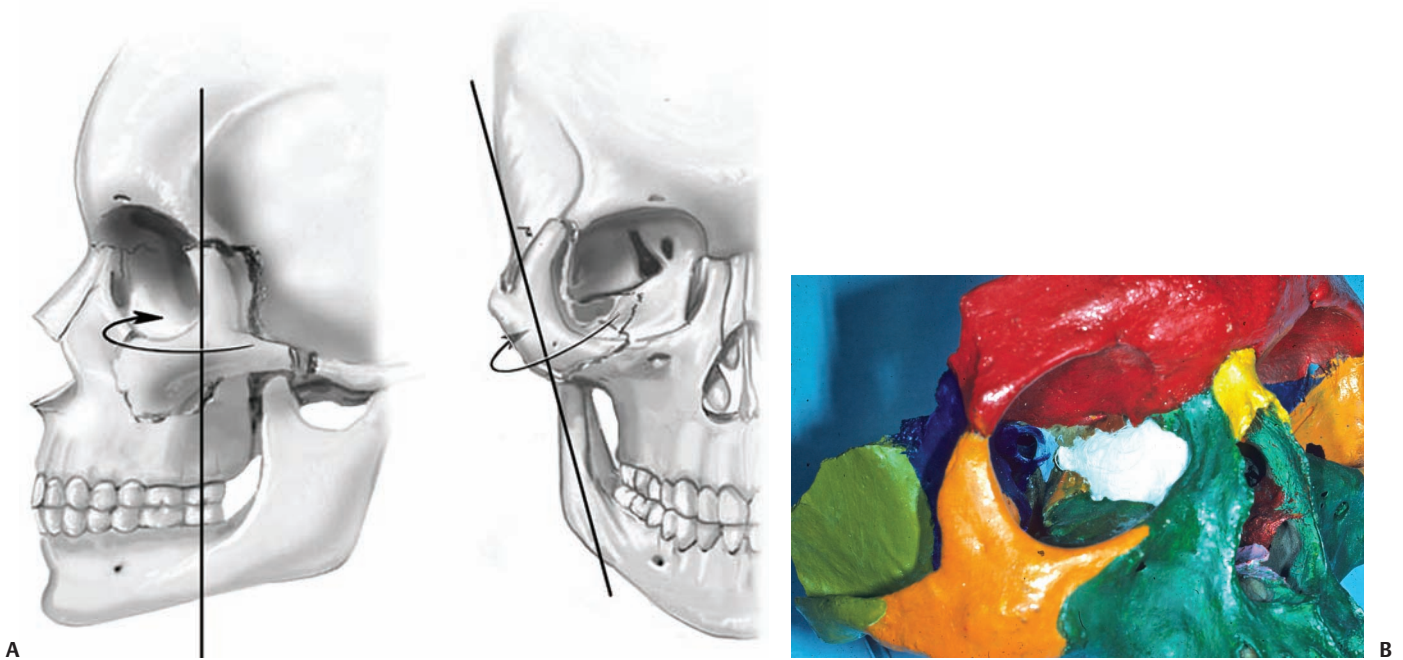


Fig. 8.30 (A, B)

malar prominence may occur, the cheek is usually *under-projected* and the face widened, because of splaying of the zygomatic arch (loss of linearity) and inward (posterior) displacement of the zygoma and its infrastructure.

“Down-out-and-back” dislocation correlates with the tendency toward cheek ptosis, temporal hollowing, lowering of the lateral canthus, lateral scleral “show,” and expansion of the orbit. Orbital volume on three-dimensional computed tomography is expanded.

In cases with “down-in-and-back” rotation, the orbit is constricted. Orbital volume by three-dimensional measurement is reduced because of (or as a result of) inward displacement of the lateral orbital wall. The compressed orbital contents are placed at risk, requiring immediate ophthalmologic evaluation and rapid operative intervention (Fig. 8.31).

Radiographic Assessment of Orbital Fractures

HRCT is required to reveal the nuances of soft-tissue injury and the extent of orbital fracture. Seldom can one depend on routine computed tomography to adequately reveal the extent of injury; 2.0-mm computed tomography and three-dimensional reformats are more revealing. The delay (to acquire additional radiographic study) and serial clinical examination favors resolution of intraorbital and periorbital edema before surgery.

Both astute radiologists and surgeons bear in mind that the risk of ocular injury is greatest when the principal fracture involves the orbit.^{47–51} Certain findings in the adult have an added risk of ocular trauma or optic nerve injury, in our experience:

- The presence of orbital soft-tissue hemorrhage
- Fractures associated with a *decreased* orbital bone volume
- Fractures of the orbital apex or greater wing of the sphenoid, notably those extending to, or near, the optic strut and optic canal



Fig. 8.31

In the presence of these stigmata, clinical suspicion is particularly elevated.^{30,42,52–56}

Orbital fractures in the adult are usefully grouped by region (Tables 8.1, 8.2, and 8.3):

- Fractures of the orbital frame
- Fractures of the orbital midsection
- Fractures of the orbital apex

Each major type and subset has distinguishing clinical and radiographic features,^{56–61} affecting greatly the decision to proceed (or not proceed) with observation or surgical intervention.^{36–38,62}

Radiographic Assessment in Children

The high cranial-to-facial proportions, the presence of cartilaginous sutures, the resilience (almost “rubbery” consistency) of pediatric bone, and a lower cortical-to-cancellous bone ratio predispose children to unique injuries. This uniqueness is often apparent upon careful study of high-resolution radiographic (HRCT) studies.

Fractures of the pediatric midsection may be less apparent, even after 1.5- to 2.0-mm cuts, yet painful diplopia and abnormal forced ductions (suggesting muscle entrapment) are present on clinical examination. The clinical findings are quite incongruent with the relatively “innocent radiographs.” It has been hypothesized that this constellation occurs because preadolescent bone is better able to bend, crack, and snap back into position in contrast to the response of relatively brittle bone of adults, which tends to buckle under stress rather than staying hinged.³⁸

In a second illustration of difference between the pediatric and adult populations, fractures in the orbital roof may obliquely traverse the superior orbital rim to join other faults in the anterior cranial vault.⁶³ These fractures are typically minimally displaced.

Radiographs of late adolescence reveal more adult-like fractures of the orbital floor^{64,65} in contrast to those of younger peers, and fractures of the orbital roof follow the more typical pattern of injury of adulthood; that is, they are more medial and near the frontal sinus and nasoethmoid complex.

Operative Repair

Management of fractures of the three components of the orbital frame is key to reconstitution of periorbital and orbital anatomy. The sequence of prealignment and repair depends on clinical and radiographic findings. In general, we prefer to prealign the superior and medial orbital frame before proceeding to the inferolateral frame and the zygomatic arch, depending on intraoperative assessment (the

Table 8.1

Orbital Frame	Region or section	Associated fracture	Associated injury	Sequelae
	Superior	Frontal bone or sinus	Cerebrospinal fluid leak (dura)	Meningitis; frontal sinusitis
	Medial	Nasomaxillary, Orbitoethmoid	Cerebrospinal fluid leak (dural tear)	Ethmoiditis and nasal obstruction
	Inferolateral	Zygomatico-orbital	Reduced orbital volume	Exophthalmos; higher risk of ocular injury

Table 8.2

Orbital Midsection	Isolated wall	Associated fracture	Associated injury	Sequelae
	Roof	N/A	Pulsatile transmission intracranial pressure	Induced alteration of facial growth within weeks
	Medial wall	N/A	Displacement of medial rectus into ethmoid sinus	Altered globe adduction without ischemia
	Lateral wall	N/A	Expanded orbital volume	Enophthalmos
	Floor	N/A	Entrapment medial rectus; trap-door deformity	Altered vertical gaze with ischemic myopathy

N/A, not applicable.

instability of each trisection of the frame) and success of prealignment with wire. Reconstitution of the midsection of the orbit then follows and, in rare cases, also decompression of the contents of the orbital apex (**Fig. 8.32**).

Incisions and Prealignment

Confirming the extent of injury and repairing most orbital fractures requires thorough exploration of the orbit and identification of numerous anatomical landmarks. Thus, exposure is key, taking into account that it is desirable to minimize postoperative scar and avoid eyelid malposition.

Three incisions provide exposure of fractures of the inferior and lateral orbital frame, orbitozygomatic complex, and orbit: coronal, transconjunctival/canthofornix, and gingivobuccal. The coronal incision across the bregma and the gingivobuccal incision in the maxillary vestibule are described in Chapters 3 and 4.

To orchestrate the canthofornix incision requires knowledge of 1) the concept of the anterior and posterior lamel-

lae²⁻⁴; 2) the anatomy of the fornix^{4,66-68}; and 3) the lateral attachments of the upper and lower eyelids to the lateral orbital frame.^{2,34,68-74}

Critical to transconjunctival execution is attention to anatomic detail, the use of contoured protective lens, and the use of atraumatic technique. Pollock and Gossman, in a review of 200 patients in 2001, emphasize the benefit of extensive, prior fresh cadaveric dissection, three- or four-power loupe magnification, the use of blunt rakes and other modified retractors (to avoid untoward trauma to the eyelid, particularly the eyelid margin), and the need for finesse in reattaching the lateral canthus to the lateral orbital frame, in those cases in which the transconjunctival incision is extended across the lateral canthal tendon.⁷³

The Concept of Lid Lamellae

Functionally, the lower eyelid has two lamellae.^{2,3} The anterior lamella contains skin, the orbicularis muscle and

Table 8.3

Orbital Apex	Region or section	Associated fracture	Associated injury	
	Superior	Sphenoid sinus	Optic neuropathy	Blindness
	Medial	Ethmoid sinus	Carotid artery injury	Posterior ethmoid sinusitis
	Inferolateral	Optic strut	Optic neuropathy	Blindness; superior orbital fissure syndrome

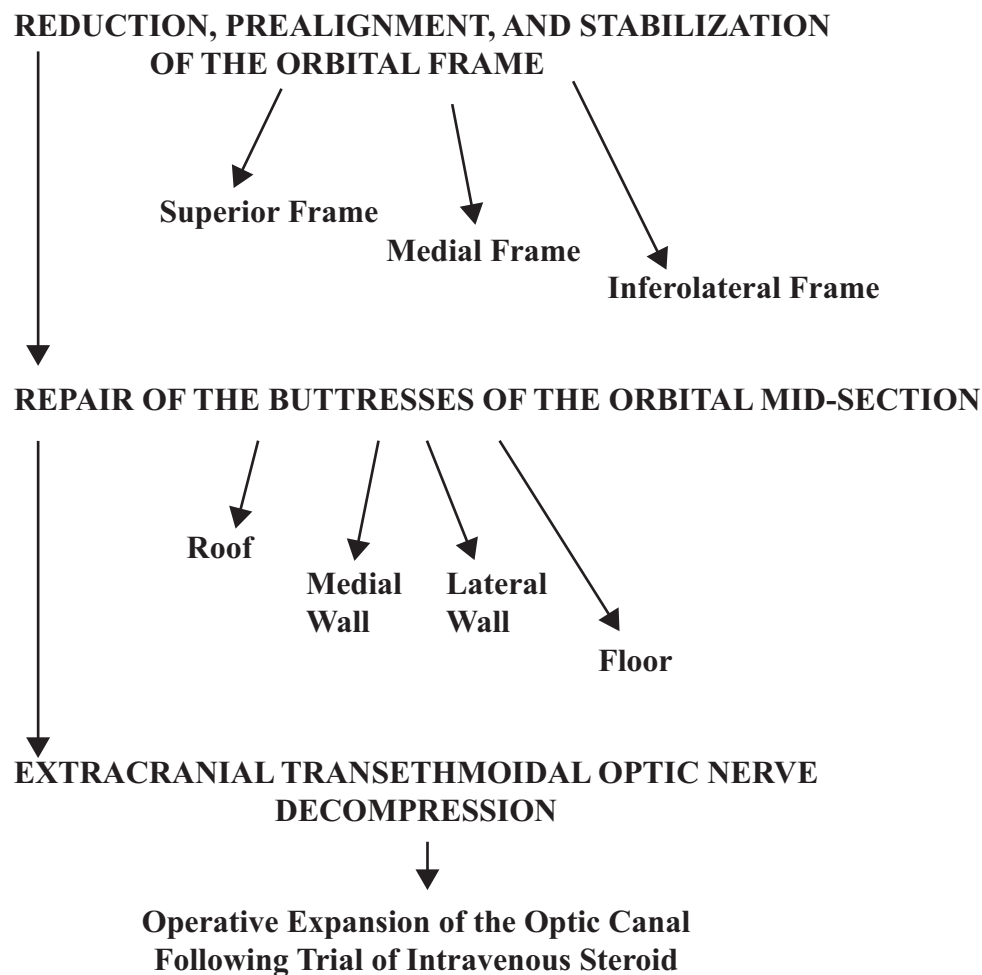
Algorithm of Repair of Orbital Frame and Orbital Fractures:

Fig. 8.32

its investing fascia, and the orbital septum. The posterior lamella of the lower eyelid includes the conjunctiva, postseptal fascia, the capsulopalpebral fascia, and the inferior tarsal muscle (the lower eyelid retractor). When transconjunctival and canthal incisions are used, the anterior lamella is not violated (thus "bypassed"), except at the lateral canthus.⁷³

The Concept of the Fornix

The palpebral and bulbar conjunctiva meet near the orbital floor in a sulcus, called the *lower fornix*.⁶⁶⁻⁶⁸ The lower eyelid retractors (the capsulopalpebral fascia and the inferior tarsal muscle) are beneath the conjunctiva of the fornix and ascend (conjoined with the orbital septum) to insert on the lower tarsus^{3,68,73} (**Fig. 8.33**).

The Canthal Incision

Operating loupes are highly advised. The lateral canthus and fornix are infiltrated with local anesthetic containing epinephrine and hyaluronidase (1.0 mL hyaluronidase added to 9.0 mL of 0.5% or 1.0% lidocaine with epinephrine). A contoured protective lens (Danker Laboratories, Sarasota, FL) is inserted prior to initiating the incision. A suture is applied to the tarsus of the *upper* eyelid and placed at gravity with a small clamp to retract the *upper* eyelid out of the way (**Fig. 8.34**).

The incision (with scalpel) begins at the lateral raphe and ascends and then descends in a subtle curve from the lateral canthus following the relaxed skin tension lines.^{68,73-76} The length of the lateral canthal incision varies but is some 0.5 cm in length in most cases, according to the extent of

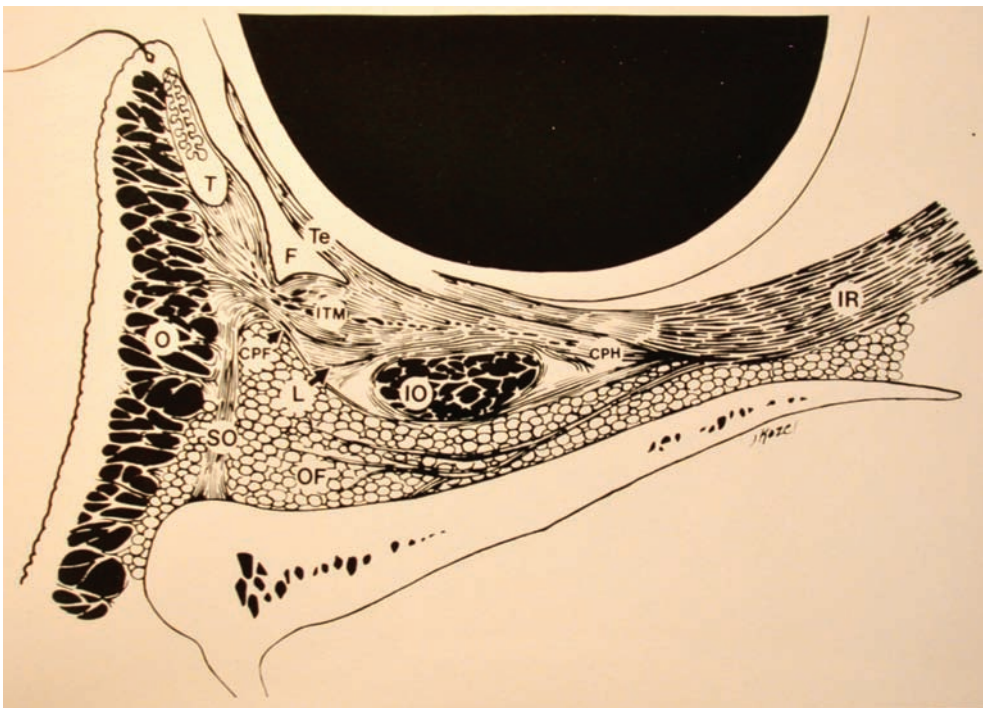


Fig. 8.33

exposure planned. After achieving the skin incision with a scalpel, an insulated needle electrocautery is used to divide the orbicularis, minimizing bleeding. Attachments of the eyelid(s) to the lateral orbital rim are located and cut horizontally with sharp tenotomy scissors or with needle electrocautery close to the lateral orbital rim; in doing so, full eversion of the lower eyelid becomes possible.

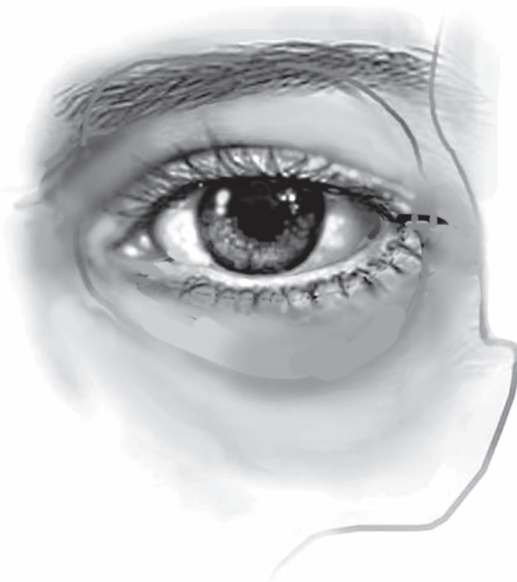


Fig. 8.34

Osseous Canthal Marker

Using the aforementioned technique for cantholysis, the upper arm of the posterior crus of the lateral canthal tendon (to the upper eyelid) is not transected and thus remains intact. In fractures limited to the orbital floor and lower medial wall, the posterior crus can later be used during closure to guide the reattachment of the lower eyelid.⁷³

In recent experience (since our 2001 publication^{73,74}), however, we have found it judicious to routinely place a partial-thickness 1.0-mm drill hole in the lateral orbital rim at the lateral canthal angle, marking the level of the lateral canthus. When surgery is redirected and a greater area of periosteal elevation is achieved than anticipated, the drill hole acts as a marker, rendering canthal repair straightforward. After the orbital floor and medial wall are repaired, for example, if it is decided to elevate periosteum superiorly along the lateral orbital wall and/or the frontal process of the zygoma, the drill hole guides the return of the canthal tendon to its prior anatomic location (Fig. 8.35).

With the osseous marker in place, the entire lateral canthal tendon may be taken down and both eyelids released from their lateral attachment.

The Lower Fornix Incision and Retroseptal Approach to the Inferior Orbital Rim

The lower lid is retracted using small sharp rakes (Blair retractors) or retraction sutures, and the lens-covered globe

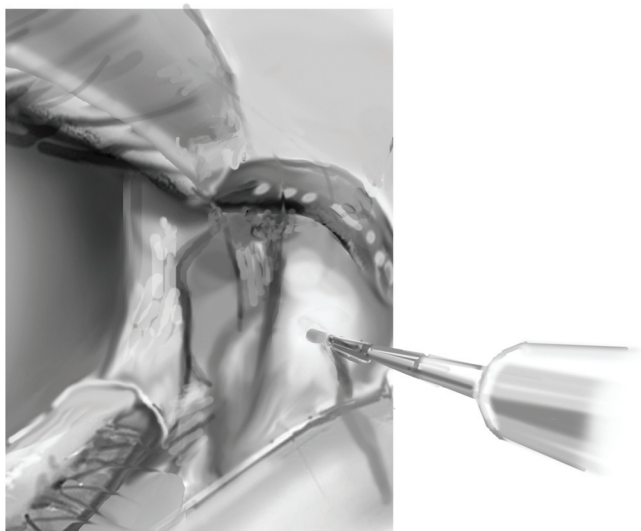


Fig. 8.35

is displaced posteriorly toward the orbital apex with an insulated, malleable retractor.

The conjunctival incision begins at the inferior pole of the caruncle in the lower fornix and parallels the curve of the globe (**Fig. 8.36**) to connect with the prior canthotomy incision at the lateral raphe. Blunt Ragnelle-Davis or Mathieu retractors are placed in the conjunctival wound, replacing the Blair retractors. The malleable retractor is advanced and also seated at the depth of the conjunctival incision. The lower lid in this way is draped over the inferior

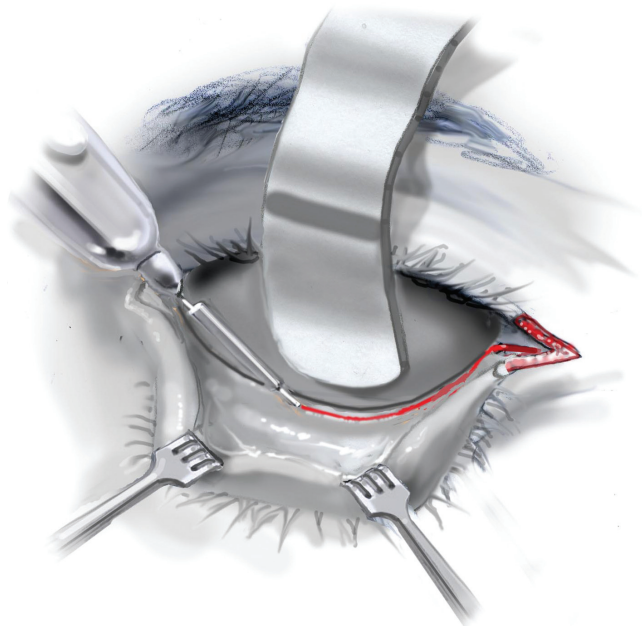


Fig. 8.36

orbital rim and fully stabilized. The incision is then carried through the capsulopalpebral retractors directly to the orbital rim using the needle electrocautery (**Fig. 8.37**). Appearance of fat confirms the retroseptal plane of dissection. Septum and orbicularis oculi are bypassed.⁷³

The Upper Fornix Incision and Preseptal Approach to the Inferior Orbital Rim

An alternate incision in the upper fornix, midway between the inferior margin of the tarsal plate and the lower fornix,⁷⁷ is chosen by some clinicians. The lower border of the inferior tarsus is identified and tented by traction. An incision is made with strabismus scissors through the conjoined retractors and orbital septum, some 2 mm below and parallel to the tarsus. *The incision should not be immediately below the tarsus* and should not extend further medially than the lacrimal punctum. Entry to the preseptal plane (between the deep fascia of the orbicularis muscle and the septum) follows. Electrocautery is minimally used (because of potential thermal damage to the orbicularis muscle or orbital septum), though hemostasis can be achieved with bipolar coagulation. When the inferior orbital rim is reached, the periorbita is incised. The corneal protective lens may be removed to permit suturing of the cephalic edge of the conjunctival wound to the upper lid margin (**Fig. 8.38**).

Elevation of the Periorbita

Periosteal elevation is initiated at the orbital rim (with a sharp Molt #9 elevator), and the fractures of the orbital frame are prealigned with wire and stabilized with plates

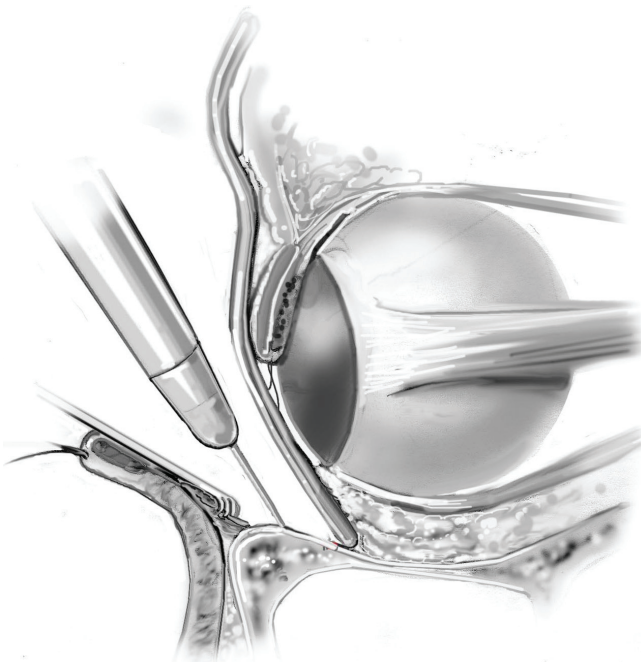


Fig. 8.37



Fig. 8.38

and screws. Repair of fractures of the midsection follows, using a commercial implant or temporoparietal bone.

Conjunctival Repair and Periosteal Suspension

In the case of the lower fornix incision, closure of the periosteum or the periorbita along the inferior orbital rim is not possible, but small drill holes along the inferior orbital rim may serve as ports to achieve resuspension. The conjunctiva is closed with a few interrupted resorbable sutures. In the case of the subtarsal incision, periosteum over the inferior orbital rim and the lateral canthus can be directly closed. The conjunctiva must be smoothly apposed with running resorbable suture.

Lateral Canthal Reattachment

Double-armed 5-0 Ethilon suture on S-22 needles (Ethicon, Cornelia, GA) is used to restore the eyelid at the lateral canthal angle. The vertical passage of the needle precisely bisects the tarsus, avoiding iatrogenic canting of the eyelid in either an outward or an inward direction, thus eyelid malposition. Both needles engage the residual periosteum of the lateral orbital rim (**Fig. 8.39**).^{68,73}

When the lateral periorbita has been widely elevated and there is no residual periosteum in the area of Whitnall tubercle, as required in the repair of complex fractures, the opportunity to attach the lids directly to periosteum has been lost. The prior shallow drill hole (so-called osseous marker) is therefore deepened to reach the orbit, and an additional hole, a millimeter or so higher, is placed in the lateral orbital rim. The drill holes should intersect in the

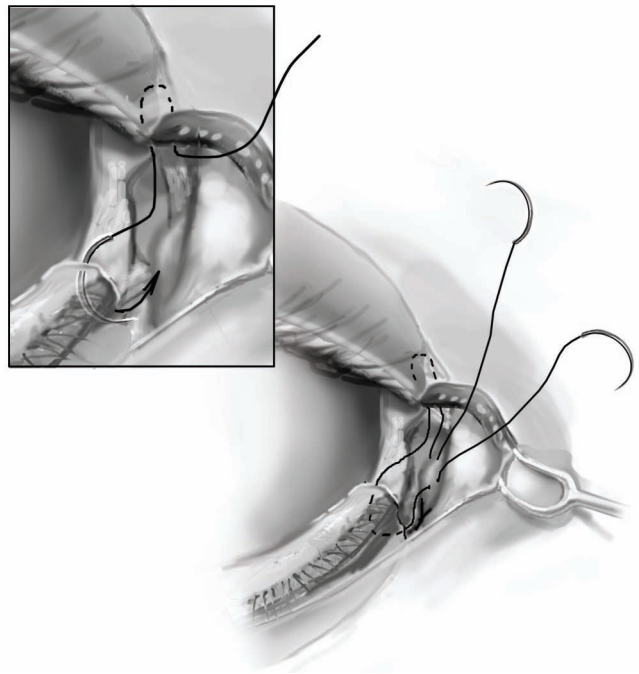


Fig. 8.39

orbit, in the area of Whitnall tubercle, allowing passage of the S-22 needles and suture (**Fig. 8.40**).

The tension upon the suture is used to align and bind the eyelids to the inner lateral orbital rim. The orbicularis muscle is secured to the inner lateral orbital rim with horizontal mattress 6-0 PDS suture.

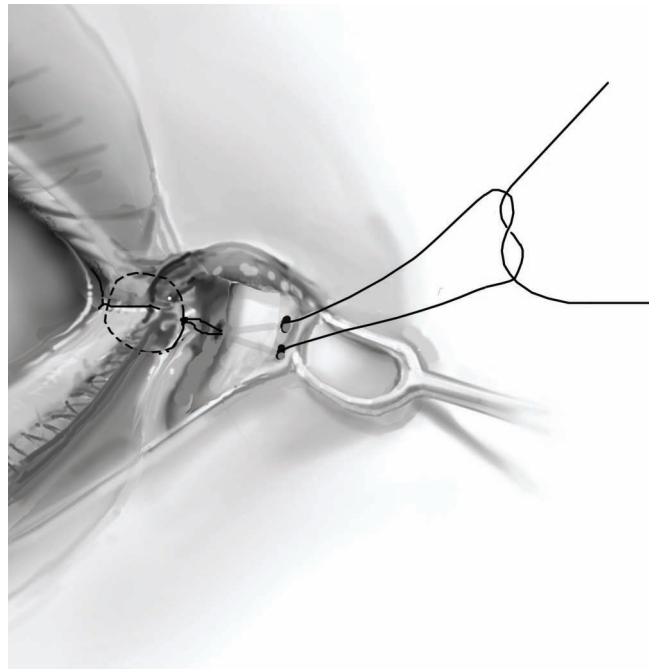


Fig. 8.40

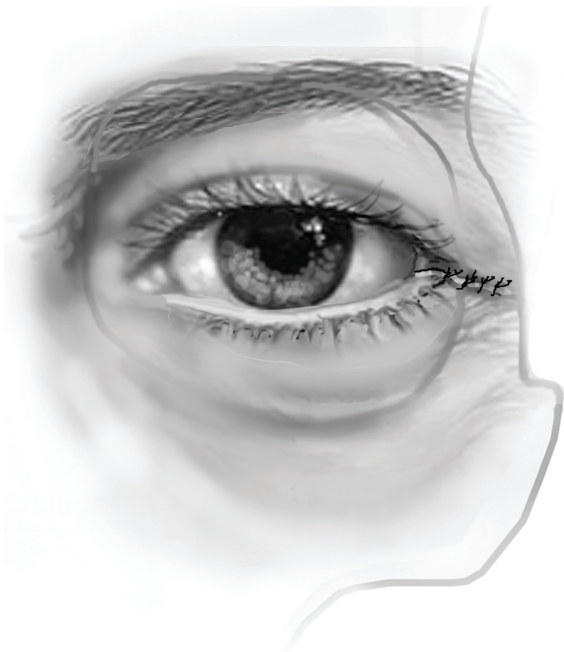


Fig. 8.41

Careful eversion of the lateral canthal skin margins upon closure with horizontal mattress 7-0 chromic suture (TG100-8 needle) minimizes scar formation. The lateral canthal wound may be buttressed by the use of rayon-reinforced strips for 48 to 72 hours and removed by the patient (Fig. 8.41).

Operative Repair

Orbitozygomatic Fractures (Lateral Orbital Frame, Zygoma, and Zygomatic Arch)

In cases with modest dislocation of the zygoma and inferolateral orbital frame, elevation may be achieved through a single, gingivobuccal incision⁷⁸ using a knurled Pollock-Dingman septal displacer or a heavy, reinforced Tessier zygoma elevator, available from Fleetwood Medical Instruments (Roseville, CA). In these cases, further incisions are waived and rigid fixation with plates and screws may be avoided.

Kelley, Hopper, and Gruss,¹⁷ and, before them, Rowe,¹⁰ however, emphasize the difficulty in correcting many orbitozygomatic fractures. With extreme rotation and displacement, disruption of the zygomatic arch, or malalignment of the orbital plate of the zygoma (lateral orbital wall), full exposure is indicated, using gingivobuccal, canthofornix, and often coronal incisions. By grasping the frontal process of the zygoma with a Kocher clamp, the zygoma can be elevated and brought into anatomic position at the FZ suture. Prealignment is secured with 24-gauge wire. The zygomatic arch should then be repaired, recreating the linear architecture needed to thrust the malar prominence forward to ensure adequate projection. Alignment is

checked at the other processes, including the alignment of the orbital plate of the zygoma with the greater wing of the sphenoid (and theoretically the optic strut of the orbital apex/lesser wing of the sphenoid), before applying plates and screws at multiple locations. We prefer the additional rigidity of a 2.0-mm or 1.5-mm plate at the FZ suture, bent to match the contour of the zygomatic process of the frontal bone. Plates that are 1.5 mm suffice across the zygomatic arch and the lateral midfacial buttress, and mini- or microplates are preferred across the inferior orbital rim.

The pull of the masseter is often underestimated and can frustrate mobilization of the inferolateral frame.¹⁷ The force of the masseter may be overcome in the following ways (Fig. 8.42):

- Muscle relaxants to temporarily paralyze the masseter during prealignment
- Partial or complete release of the anterior portion of the masseter from the temporal process of the zygoma
- Prealignment at the FZ suture, using 24-gauge wire, as previously noted
- Broad elevation of the periosteum over the malar prominence of the zygoma and over the anterior portion of the zygomatic arch

Once proper prealignment and rigid fixation of the zygoma and orbital frame has been assured, attention is directed to the orbital midsection.

Fractures of the Orbital Midsection

Repair of the orbital midsection may be far more complex than cursory study suggests, as noted by Cole and colleagues.⁴⁰ Dimensions and placement of commercial implant(s) or split cranial bone graft(s) are keys to restoring midsection anatomy and adequate orbital volume.

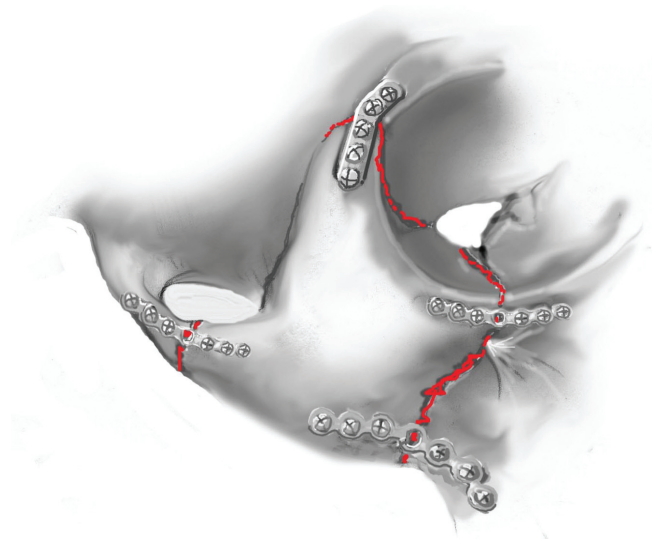


Fig. 8.42

Implants of porous polyethylene embedded with titanium or other metal alloy (Medpor® [Porex Surgical, Inc./Stryker Corporation, Kalamazoo, MI] and Synpor® [Synthes Craniomaxillofacial, Paoli, NJ]) have greatly facilitated repair of small and some moderately sized defects of the orbital midsection, despite their linearity. The lack of complexity of these fractures relatively warrants a satisfactory outcome, and the embedded implant may be readily secured to the orbital rim, with one or two screws. As complexity of orbital fracture increases, however, so does the possibility of postoperative enophthalmos *when a linear implant is utilized*. In this setting in my practice, I have been able to improve outcomes in the orbital midsection by reshaping the embedded titanium implant by hand, such that the implant better mimics normal anatomic contour of the affected area(s) of the orbit. The bilge of the anterior and posterior floor, ethmoid jut, and the anteromedial floor are sites of fracture that come to mind. Duplication of normal anatomy in these areas, it seems, may only follow the development of commercial implants that are precontoured at the time of manufacture.

In our hands, bone has great utility when the defect exceeds 2.5 cm and there are multiple fracture sites. The contour of split cranial bone, particularly when taken from the temporoparietal skull, nicely mimics the natural contours of the orbit. The excellent blood supply in the orbit also minimizes the risk of resorption, as does slight “overfilling” to compensate for edema. The size of defects in the posterior midsection is often underestimated, and the surgeon is well served by circumspection and the use of several grafts in the posterior bilge, the posteromedial wall, or the posterior orbital roof. Fit is optimized by grooving the perimeter of the grafts, creating “top-hat” grafts or “shives,” so that the recipient defect acts as a mortise.

The Orbital Roof

Fractures of the orbital roof tend to be displaced inferiorly as a “blow-in” fracture, and the globe is correspondingly displaced downwardly and outwardly (exophthalmos) as a result of the reduced orbital volume. Upward gaze may be restricted by the inferiorly displaced fragment. Roof fractures may be isolated but often accompany fractures of the anterior table of the frontal sinus or superior orbital rim.

Anterior “blow-in” roof fractures are repaired with a commercial implant or a “top-hat” graft secured at the superior orbital rim. “Blow-in” fractures of the posterior superior orbit are best repaired with a “top-hat” bone graft placed from above using a neurosurgical approach; they usually do not require rigid fixation (**Fig. 8.43**).

The Medial Orbital Wall

Medial wall fractures may be isolated (“pure”) or associated with fracture of the orbital floor. In some isolated



Fig. 8.43

medial “blow-out” fractures, the lamina papyracea is displaced as an intact slate that is hinged posteriorly. This en bloc displacement, referred to as a “hinged blow-out fracture” may be favorably returned to position with a Rudderman, Tenzel, or Freer elevator, precluding use of a graft or alloplastic (commercial) implant (**Fig. 8.44**).

Some medial wall fractures are large enough to allow displacement of the medial rectus muscle into the anterior and posterior ethmoid sinus. Soft-tissue incarceration in these cases is few and far between. *Spicules of the lamina papyracea, at the margins of smaller “blow-out” fracture of the medial wall, however, may hinder release of the muscle.* In these cases, dissection from below (via the lower fornix) and above (via a coronal incision) may be needed to free the muscle atraumatically. If dissection above and below the fracture fails, the fracture is best enlarged by removing

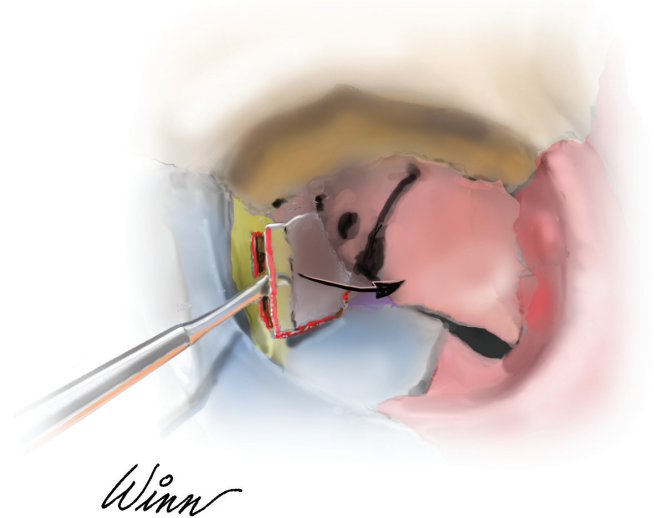


Fig. 8.44

part of the comminuted fragments, then reconstructing the larger defect.

The contribution of the lamina papyracea (“ethmoid jut”) to decreased orbital volume should not be underestimated, particularly in males. When reconstructing the medial orbital wall, I have resorted in some cases, as noted previously, to manipulating embedded polyethylene by hand to gain the proper convexity in the area of the jut, with the added advantage that the plate can then be fixed to the medial orbital rim with a single screw. In other cases, for example when the posterior medial wall is involved by fracture, I have harvested temporoparietal outer cortex, beveled the edges with a cutting burr, and wedged it into the residual medial wall of the posterior ethmoid sinus, in mortise-like fashion. The convexity of the graft, like the modified commercial implant, is directed into the orbit, to mimic the ethmoid jut. The graft may be readily secured to the medial orbital rim, if a “bone assembly” (Chapter 3) is created, before insertion.

When fractures of the orbital floor and medial orbital wall coexist, the floor is first reestablished with graft or a commercial, polyethylene implant. The floor graft then serves as a platform upon which the medial wall can be reconstituted.⁴

The Orbital Floor

Management of isolated “blow-in” and “blow-out” fractures of the orbital floor created controversy for several decades, prolonged observation (4 to 6 months), and untoward delays in surgical intervention.^{36–38} In 1991, reports by Putterman³⁸ and by Manson and Iliff³⁶ brought the controversy to a relative close,^{36–38} favoring a varied response in the presence of midorbital floor fracture, depending on radiographic and clinical findings. Improved outcomes have followed their collective recommendations.⁴⁰ Recent experience has been delineated by Yano and colleagues.⁴¹

Early operative repair by consensus is indicated in patients with orbital floor fractures when there is evidence of:

- **C:** entrapment by HRCT
- **D:** nonresolving diplopia
- **E:** enophthalmos OR
- **F:** a “positive” forced duction test, such that upward movement of the globe is restricted

The acronym CDEF is a useful reminder of the criteria that suggests the need for operative intervention. In the presence of entrapment by clinical exam (F) and radiographs (C), surgery is best quickly pursued.

To assess the extent of injury and to reach the *preannular* (posterior) shelf requires:

- Thorough exploration of the entire orbital floor, beginning laterally and proceeding posteriorly and medially
- Identification of the location of the infraorbital nerve

Elevation of the periorbita can be achieved with one of a host of elevators. As most fractures of the floor are *medial*, subperiosteal dissection to expose them usually begins at the *lateral* orbital rim in areas uninvolved by the fracture, and only then extends posteriorly and medially to reach the inferior orbital fissure. The infraorbital nerve is recognized as a faint, yellow, linear stripe beneath bone a few millimeters deep to the orbital rim. It is usually covered by bone that is thin but on occasion is absent. The nerve is usually on line with the zygomaticomaxillary suture, but on rare occasions is noted within the orbital plate of the zygoma.⁴

Once the lateral extent of the fracture is exposed, the medial and posterior limits of injury are determined. The origin of the inferior oblique muscle is usually released during the periosteal elevation along the anterior medial floor and lower medial wall. The orbital contents are lifted, hand over hand, using contoured malleable retractors, as the preannular shelf is approached.

When the main fragment of the floor is hinged medially, as it tends to be in isolated fractures, the orbital plate is depressed into the maxillary sinus just enough to allow the surgeon to elevate the incarcerated soft tissue from the sinus with an elevator. In cases resistant to atraumatic elevation of the entrapped tissue, the fracture may be enlarged. The entrapped tissue should be elevated as atraumatically as possible and should not be amputated, sheared, or pulled forcefully from the site of entrapment. Proper lighting and magnification (loupes) aid the release of the incarcerated tissue, and malleable retractors ensure proper placement of grafts or implants.

Quite small defects of the orbital floor need not be repaired. Moderately sized defects (greater than a square centimeter) are best bridged, however, with alloplastic material. The orbital contents are held upward with a curved, malleable retractor, and the linear implant is advanced to lie upon the preannular shelf, then (in some but not all cases) secured with one or two screws at the orbital rim. The commercial implant offers adequate support to the globe and precludes recurrent herniation of orbital contents. In some instances, when a large floor defect is present, I have resorted to reshaping an implant embedded with titanium with my thumb and fingers, in the hope of better matching the bilge of the orbital floor.

When the complex contours of the orbit have been *highly disrupted* and the orbital defect(s) are extensive, the relative linearity of alloplastic material fails to restore a sufficiently anatomic reduction, leading to postoperative enophthalmos. Available commercial implants cannot yet compete under these highly complex circumstances and succumb to the relative success of bone grafts. The contour of temporoparietal bone nicely mimics the downward concavity of the anterior orbital floor (anterior bilge). The contour of the bone, if inverted, also nicely matches the upward slope (convexity) of the posterior bilge, as the *preannular shelf* is reached (**Figs. 8.45 and 8.46**).

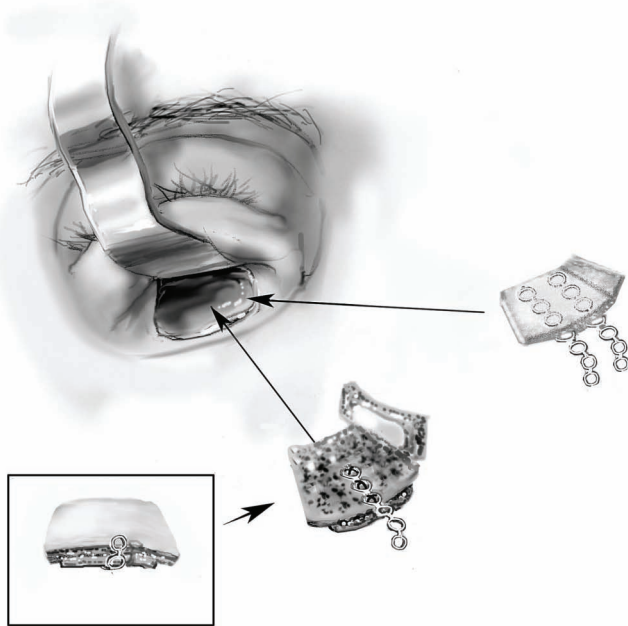


Fig. 8.45

Resting the deeper limit of the bone graft on the preanular shelf assures posterior stability, and *convexity* (outer cortex) of the temporoparietal graft simulates the upward slope of the posterior orbital bilge. *Concavity* of the underside (spongiosa) of temporoparietal bone simulates the downward slope of anterior bilge deep to the inferior orbital rim. One end of the microplate is secured to the graft before its insertion (thus creating an “assembly”) (see Chapter 2), and the other end of the plate is bent in an S-shape to adapt to the orbital rim before being secured with screw(s).



Fig. 8.46

When multiple grafts are required, the floor is first re-constructed. Only then is the medial wall reestablished with an implant or a temporoparietal bone graft.

Fractures of the Lateral Orbital Wall

The orbital plate of the zygoma is less able than sphenoid and frontal bone to bear impact⁴ and may assume an accordion-like appearance on radiographs.¹⁹ In others, a 1.0-cm to 1.5-cm segment of the deepest part of the orbital plate fractures. Orbital fat under these circumstances may herniate from within the orbit to the temporal fossa, adding to enophthalmic sequelae and possibly entrapment. The entrapped fat is released prior to buttress realignment.

Prealignment with 24-gauge wire at the FZ suture allows the surgeon to rotate the zygomaticomaxillary complex into position, such that the inferior orbital rim, the lateral maxillary buttress, the orbital plate of the maxilla and the greater wing of the sphenoid, and the zygomatic arch are in proper alignment. Assured of proper reduction, fixation with plates and screws is achieved, except at the zygomaticosphenoid suture. Seldom is a bone graft or a commercial implant to the lateral orbital wall required. Release of an entrapped lateral rectus is carefully achieved, but, unlike medial wall entrapment, seldom does the defect have to be enlarged to release the herniated tissue.

Impact sufficient to fragment the lateral orbital wall has been associated with acute visual loss at the time of injury. Radiographs upon evaluation may “paradoxically” reveal *neither* displacement of the optic strut microbuttress *nor* narrowing of the optic canal. Acute visual loss has also followed surgical reduction of lateral wall fracture, though the incidence of postoperative blindness is admittedly rare.^{79–84}

Fractures of the Orbital Apex

Consensus regarding the medical and operative management of fractures of the orbital apex was reached in much the same timeframe as the consensus regarding early-versus-late repair of orbital floor fractures: extracranial transthemoidal optic nerve decompression was shown in 1990 to rescue approximately half of those patients with visual loss *that did not respond to the acute (trial) infusion of steroids*.⁸⁵

The management of optic neuropathy is discussed in the ensuing section on collateral damage, including mention of evidence that some optic neuropathies and selected cases of spinal cord trauma benefit from high (so-called neurosurgical) doses of dexamethasone, allaying the need at least in those cases) for surgical intervention.

Approach to Collateral Damage

Globe Injuries

The zygoma typically dislocates downwardly, outwardly, and laterally, expanding the orbit. In those few cases when the rotation occurs medially and inwardly, the orbit and globe are constricted. Ophthalmological consultation is advised when the latter (a constricted orbit) is present on HRCT and/or when exophthalmos is present upon clinical examination. Commotio retinae, a form of detachment of the retina, is routinely sought during preoperative and postoperative examination^{86,87} but is particularly suspected in this clinical and radiographic setting.

Optic Nerve Injury

Visual loss following fracture repair is most often attributable to increased orbital pressure secondary to hemorrhage or edema, leading to ischemic optic neuropathy. Orbital pain and proptosis typically precede visual loss, and HRCT is indicated to rule out orbital hematoma and shifting of the orbital implant(s).⁴

Red color desaturation is an early sign of compromise of the optic nerve. The nonophthalmologist may test desaturation by simply placing a penlight behind a raised finger; the patient is then asked to declare the color perceived.⁴⁶ Wang and colleagues note that initial visual acuity reliably predicts final outcome. Patients presenting with visual acuities of 20/400 or better typically recover some vision, regardless of treatment modality. Few patients that present with blindness, however, regain sight without intervention.^{45,46}

High, “neurosurgical” doses of steroid have been shown to improve altered visual acuity in the acute setting. Steroid use dates to the 1980s, when other optic neuropathies and spinal cord trauma⁸⁸ were shown to respond to 1.0 mg/kg dexamethasone loading and 0.5 mg/kg every 6 hours thereafter.^{42,46}

Extracranial transethmoidal optic nerve decompression is advised if steroid infusion fails or is minimally successful, because restoration of some (or all) vision occurs in greater than two of three affected cases.⁸⁵

Ocular Motility Injuries

Acute ocular motility problems and diplopia may fail to resolve following surgery. As scar forms within the orbit (perhaps about and within ocular muscle), motility may be compromised.

These patients are best referred to strabismus specialists for evaluation as possible candidates for eye-muscle recession, despite recognition that diplopia may alternatively

be neuropathic due to injury to the brainstem or peripheral nerve branches.

Nasolacrimal Duct Damage

If the canicular system is damaged, it is repaired (following silicone Crawford intubation) with fine sutures. The silicone is left in position for some 60 to 90 days, but repair may still fail and thus lead to secondary, corrective procedures,^{89–91} such as lacrimal bypass surgery, using a (Lester) Jones tube.

Orbitozygomatic and/or Globe Malposition

When projection of the malar prominence is inadequate postoperatively (evident by subtle, downward displacement of the lateral canthus and “scleral show”), asymmetry is usually apparent after resolution of intraorbital and periorbital swelling. Enophthalmos, as a result of the expanded orbital volume, becomes increasingly apparent and is confirmed by computed tomography. Intraoperative computed tomography or C-arm⁹² radiographs would reduce the incidence of orbitozygomatic malposition.

Contour of the orbit (floor, walls, or roof) may not be restored despite experienced hands, whether bone, commercial implant, or both are used. Restitution of the posterior orbital bilge (floor) and the posterior medial wall is notably difficult; this in part follows the insertion of bone grafts or commercial implants that are linear and do not sufficiently match the contoured architecture of the orbit, as noted previously.

Enophthalmos has many causes: failure to restore the contoured architecture of the orbit; bone graft resorption; linearity of commercial implants or bone grafts; and soft-tissue (orbital fat) atrophy are but four. Occult defects in the posterior medial wall, the orbital floor, or the posterior medial roof are additional causes. Malposition of the grafts or commercial implants may be an iatrogenic, causative variable.

Some patients opt for camouflage procedures, such as subtle deepening of the opposite superior sulcus, injecting fat in the affected superior sulcus, or placement of dermis fat graft in the hollowed superior sulcus, when enophthalmos is present.

Eyelid Scar and Malposition

The lower eyelid appears to be vulnerable to operative intervention, such that outward tilt of the eyelid (*ectropion*) may follow incisions or dissection in the *anterior* lamella, and inward tilt (*entropion*) may occur after incision and dissection in the *posterior* lamella. Precise suture closure and suture tarsorrhaphy appear to reduce the incidence of postoperative scar and lid malposition so that loupes and meticulous repair are achieved.

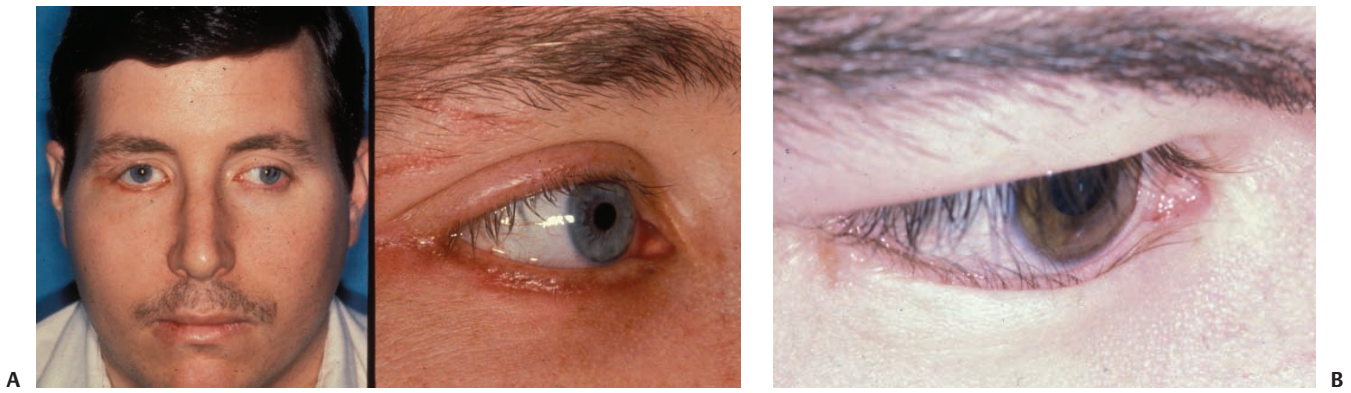


Fig. 8.47 (A, B)

The incidence of ectropion after *subciliary* incision and dissection in the preseptal plane is a common occurrence (Fig. 8.47A), and the incision in our experience has been relegated to use only in special circumstance. Incision in the *upper fornix* (subtarsal), *undertaken too closely to the tarsus, and dissection in the preseptal plane* may carry similar risk.⁹³ The *lower fornix* incision is not exempt from entropion, but the incidence in our experience appears to be minimal (Fig. 8.47B).

Lower fornix incisions and canthotomy (canthofornix approach) offer the following benefits:

- Dissection of the orbicularis oculi fibers is precluded and the anterior lamella avoided, except at the lateral canthus
- Bleeding is safely controlled with electrocautery
- Scar is relatively hidden by the natural wrinkle at the lateral canthus
- The incidence of lid malposition is reduced

For these reasons, in our hands, a transconjunctival incision in the lower fornix, with or without canthotomy, has become a preferred approach to the lower orbit.

Eyelid malposition is repaired by lid repositioning and canthopexy.^{94,95}

Infraorbital Neuralgia

Persistent dysesthesias in the distribution of the infraorbital nerve are a common complaint following comminution of the inferior orbital rim and/or fracture(s) in the area of the infraorbital foramen. The unrelenting pain may be due to pressure from an implant or graft in the orbital floor, and in these cases, the neuralgia abates following repositioning of the implant or graft. In others, there is no apparent offending cause.

Graciously, the pain abates with patience, usually within 6 to 8 months. During the interim, carbamazepine offers

partial control. In others, the problem is solved only by enlargement of the infraorbital foramen and decompression of the affected nerve.¹⁹ Cases with residual neuralgia otherwise end up in the hands of pain management specialists to gain relief.

Exemplary Repair

Case 12. Inferior Orbital Rim and Anterior Orbital Floor Fractures, Associated with Anterior Lamellar Laceration

This utility contractor struck the rung of a utility pole, suffering a laceration of the anterior lamella, comminution of the central inferior orbital rim, and a blow-out fracture of the anterior orbital floor. The globe was spared, except for corneal abrasion (Fig. 8.48A,B).

The rim was prealigned with wire and stabilized with microplates. The large anterior orbital floor fragment was elevated with a Rudderman elevator; it clicked into position but was overlaid with conchal cartilage. The canthofornix incision bypassed the laceration of the lower medial eyelid. The latter was closed with a running vertical mattress cross-stitch using 7-0 nylon on a custom needle. Sutures were removed 4 days after surgery. The patient is finally pictured at year 4 (Fig. 8.48C).

Case 13. Orbital Floor Fracture with Polyethylene Implant

This 17-year-old boy suffered trauma to the periorbital area and a blow-out fracture of the midorbital medial floor and medial wall with entrapment of the inferior rectus muscle. Rapid intervention followed, with release of the entrapped orbital contents following a transconjunctival incision. The defect was enlarged slightly medially to facilitate safe release of the orbital contents (Fig. 8.49A-E).



Fig. 8.48 (A–C)

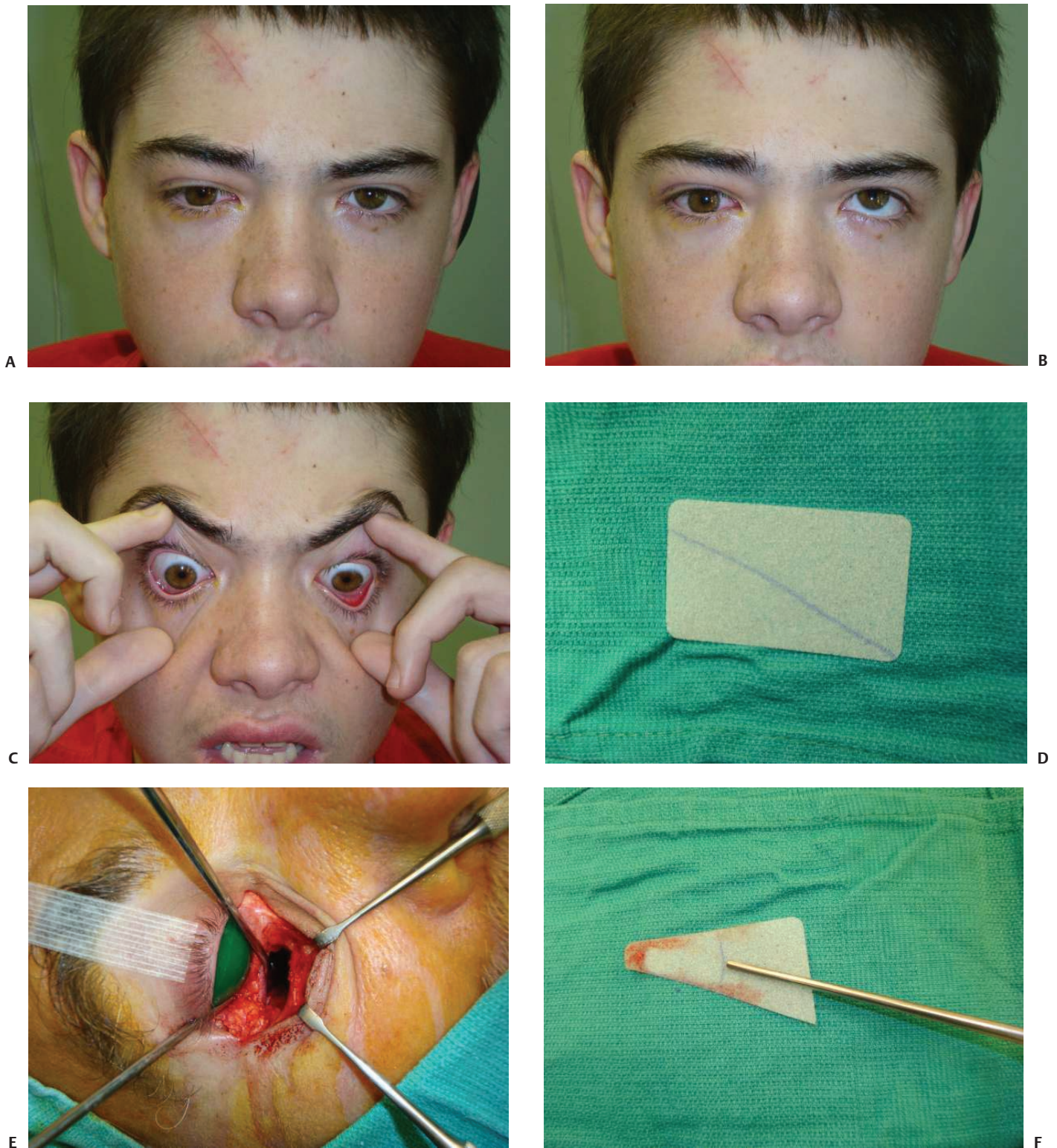


Fig. 8.49 (A-F) (Continued)



Fig. 8.49 (Continued) (G–J)

A commercial implant was trimmed to a triangular shape and measured $38 \times 50 \times 0.85$ and placed on the preannular shelf posteriorly and the anterior floor anteriorly, deep to the intact inferior orbital frame. The implant was rotated slightly medially to concomitantly bridge a small cleft in the lower medial wall. Before placement of the implant, the orbital contents were elevated with a malleable retractor, and the preannular shelf and the posterior wall of the maxillary sinus were visualized (Fig. 8.49F–H). Forced ductions were excellent prior to approximation of the conjunctiva.

The patient is finally pictured approximately 2 months following surgery. Periorbital edema is seen to be abating, and globe motility progressively improving. Vertical diplopia is limited to downgaze, pending a return of lower eyelid retractor function (Fig. 8.49I, J).

Case 14. Orbitozygomatic and Orbital Floor Fracture using a Polyethylene Implant

A 38-year-old man suffered a fracture of the left zygoma, comminution of the zygomatic arch, and an ipsilateral orbital floor fracture during basketball. The zygomatic and zygomatic arch fractures were reduced by way of coronal and gingivobuccal incisions, and the orbital floor fracture was exposed by means of a lower fornix incision and lateral canthotomy. The floor defect was bridged using a polyethylene implant. Rigid four-point fixation of the zygoma was achieved (the appliance at the frontozygomatic suture placed through the lateral canthotomy incision is not pictured). Suture fixation of the upper and lower eyelids was achieved by way of a common drill hole in the lateral orbital wall/frontal process of the zygoma). The postoperative view was taken some 2 years following the injury (Fig. 8.50A–F).

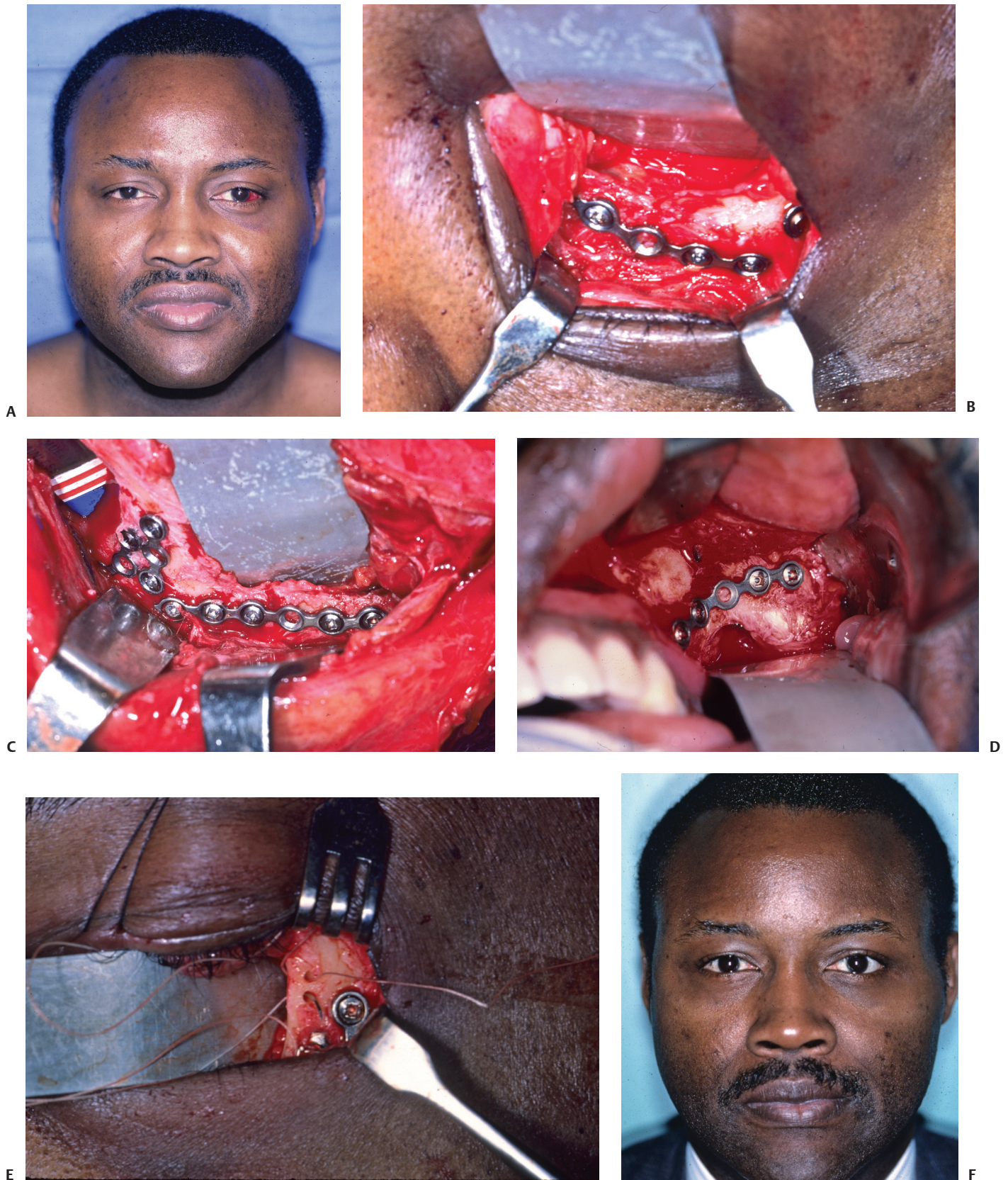


Fig. 8.50 (A-F)

Case 15. Fractures of the Orbitozygomatic Complex and Orbital Midsection

This young adult was involved in a motor vehicle accident and incurred “blow-out” fractures of the left orbital floor and posteriomedial wall and down-back-and-out displacement of the left zygoma. The orbit is expanded (**Fig. 8.51A–C**).

Impairment of downward gaze is apparent, and large fractures of the lacrimal bone and anterior medial orbital wall (left orbitoethmoid buttress) are evident by HRCT. Note the “spectacle hematoma.” The zygoma was elevated and secured with rigid fixation, as was the inferior orbital rim. Large grafts preassembled to a titanium “fan” appliance restored the continuity of the orbital floor and posteriomedial orbital wall. Left gingivobuccal and canthofornix incisions were used (**Fig. 8.51D–G**).

Case 16. Lateral Orbital Frame and the Orbital Midsection

The orbitozygomatic complex is displaced outwardly, downwardly, and backwardly. The lateral orbital wall had an “accordion” appearance on HRCT. “Blow-out” fractures were apparent in the floor and anterior and medial posterior walls. There was no evidence of temporal lobe contusion on magnetic resonance imaging. The displaced zygoma was elevated into position and stabilized at the FZ suture and two other points of fixation. A Le Fort I maxillary fracture was also reduced and stabilized with plates and screws. The infraorbital nerve, though exposed by the fracture line, was protected.

With the orbital frame realigned, three grafts were inserted to restore the orbital floor and the posterior and anterior orbital wall; the graft in the bilge was secured to the inferior orbital rim. The other grafts “snapped” into position without fixation. The lateral canthofornix and other incisions were closed. Patient is pictured at 3 years (**Fig. 8.52A–H**).

Case 17. Anterior and Posterior Orbital Floor and Medial Wall Fractures

A very large “blow out” fracture of the bilge of the left orbit occurred following a motor vehicle accident. Left upward gaze was restricted leading to early intervention. Subtle preoperative enophthalmos was apparent despite periorbital edema (**Fig. 8.53A,B**). HRCT and three-dimensional reformatting revealed marked orbital expansion.

After canthofornix and coronal incisions, three grafts were inserted, the first of which was inserted with convexity of the graft directed *upwardly* in an attempt to reconstitute the anatomical ascent of the posterior floor (posterior bilge). The second floor graft was inserted with the convexity downward, so that the contour of the graft mimicked the anatomical architecture of the anterior bilge

1.5 to 1.6 cm behind the inferior orbital rim (**Fig. 8.53C–E**). The third graft, with the contour projecting into the orbit, mimicked the normal contour of the ethmoid jut and thus the anatomical contour of the medial wall.

Chemosis occurred in the immediate postoperative period but was treated with dexamethasone ophthalmic steroid drops. Mild scleral show responded to serial (upward-and-outward) massage of the left lower eyelid. The patient is pictured 2 and some 4 years after the repair (**Fig. 8.53F,G**).

Case 18. Right Upper and Lower Midfacial (Zygomatic and Maxillary) and Orbital Comminution with the Use of Rib Grafts

Anterior and posterior orbital floor, lateral orbital wall, and right zygomaticozygomatic comminution followed a soccer ball impact (**Fig. 8.54A**).

Rib graft was used to restore the malar prominence and lateral maxillary buttress beneath the malar prominence (**Fig. 8.54B**). Floor and lateral orbital wall reconstruction (with rib grafts contoured using Tessier forceps) followed.

A right canthofornix incision, one of three used to reduce and stabilize the fractures, is depicted (**Fig. 8.54C**). The canthotomy wound is depicted in the immediate postoperative period, after suture removal (**Fig. 8.54D**).

Follow-up some 2, 5, and 7 years after surgery is depicted (**Fig. 8.54E–G**).

Case 19. Orbitozygomatic Complex and Orbital Floor Fractures

This graduate student athlete fell from a bike, suffering soft-tissue injuries, including a laceration of the right upper eyelid and fractures of the ipsilateral zygoma, orbit, and maxilla (**Fig. 8.55A,B**).

Radiographs confirmed the extent of injury suggested by clinical examination: the zygoma, zygomatic arch, maxilla, and orbit were comminuted. At surgery, the periosteum overlying the malar prominence was totally elevated. The zygoma was grasped with a Kocher clamp and elevated to proper height, rotated into position, then prealigned with 24-gauge wire at the zygomaticofrontal suture. Plates and screws stabilized the orbital frame and the zygomaticomaxillary complex.

Small bits of bone, shredded mucosa, and blood clot were removed by suction and irrigation. Four grafts for the orbital floor and medial wall were harvested from the temporoparietal skull (outer cortex), two of which are shown (**Fig. 8.55C,D**). The graft with the convexity down matched the contour of the bilge of the floor, and the other grafts restored the ethmoid jut and posteromedial floor (not shown).

The lateral canthus was repositioned 2 mm above the level of the medial canthus (**Fig. 8.55E**).

Sutures of the upper eyelid and canthus were removed at 4 days, to avoid so-called stitch marks.



Fig. 8.51 (A-G)

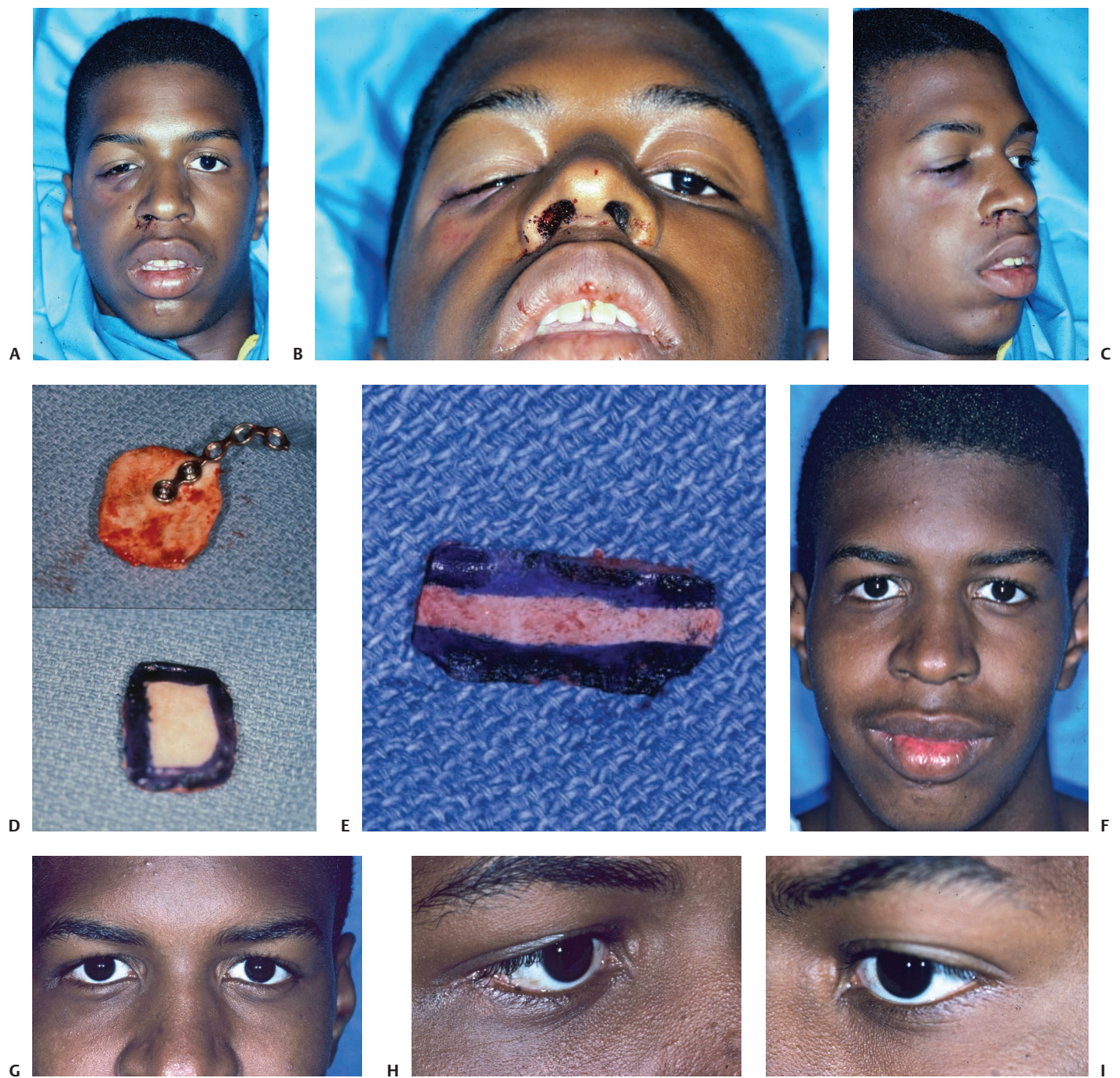


Fig. 8.52 (A-I)



Fig. 8.53 (A-G)



Fig. 8.54 (A-G)

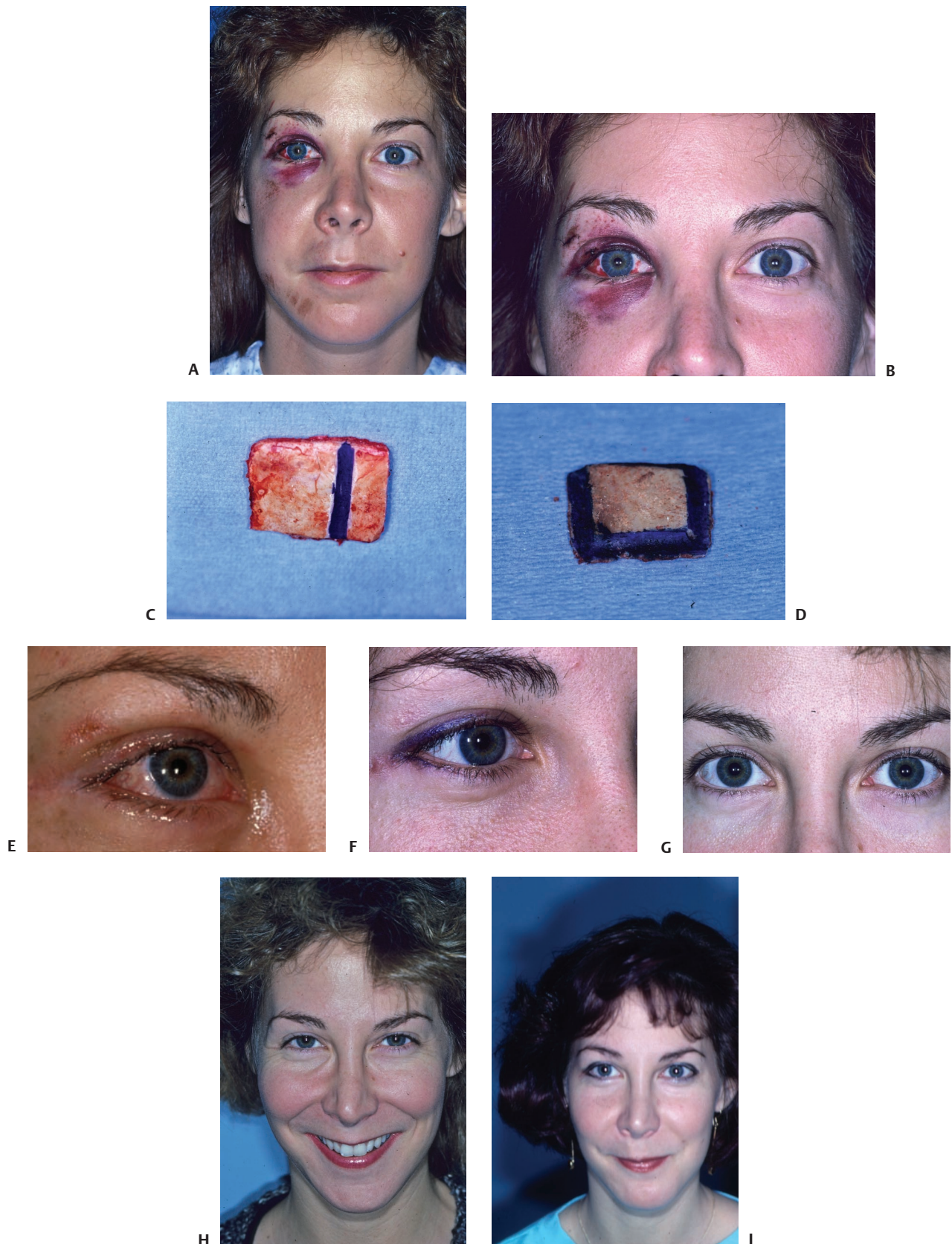


Fig. 8.55 (A-I)

The benefit of lower eyelid “bypass,” achieved with the canthofornix incision, is evident at an early stage (**Fig. 8.55F**).

The patient is shown 1, 3, and 7 years after surgical intervention. Extraocular eye movements were restored in full, accompanied by excellent periorbital cosmesis and proportion (**Fig. 8.55G–I**). The patient did not seek excision of occult “strip alopecia,” a result of the coronal incision.

Case 20. Fractures of the Mandible, Orbitozygomatic Complex, and the Orbital Midsection

Multiple fractures and an increase in orbital volume followed a vehicular accident involving heavy equipment (**Fig. 8.56A–C**).

Facial asymmetries were noted in preoperative photographs. The zygoma was displaced in a downward, outward,

and backward direction. According to three-dimensional reformatting, the orbit was expanded.

There were no fractures of the palate, allowing intermaxillary fixation and initial repair of the dentulous mandible (**Fig. 8.56D**).

The zygoma was reduced from below (with a Tessier elevator) and from above (with a Kocher clamp), prealigned with 24-gauge wire, then stabilized with a 2.0-mm plate at the frontozygomatic suture (**Fig. 8.56E,F**).

Numerous bone grafts restored the inferomedial floor (**Fig. 8.56G**), posteromedial orbital wall, and anterior maxillary wall.

One-year follow-up is pictured (**Fig. 8.56H,I**). At year 3, the patient complained of exorbitism and, when asked to extend the upper extremities, exhibited tremor. An enlarged thyroid was noted upon palpation, and hyperthyroidism was confirmed by laboratory studies (**Fig. 8.56J,K**).

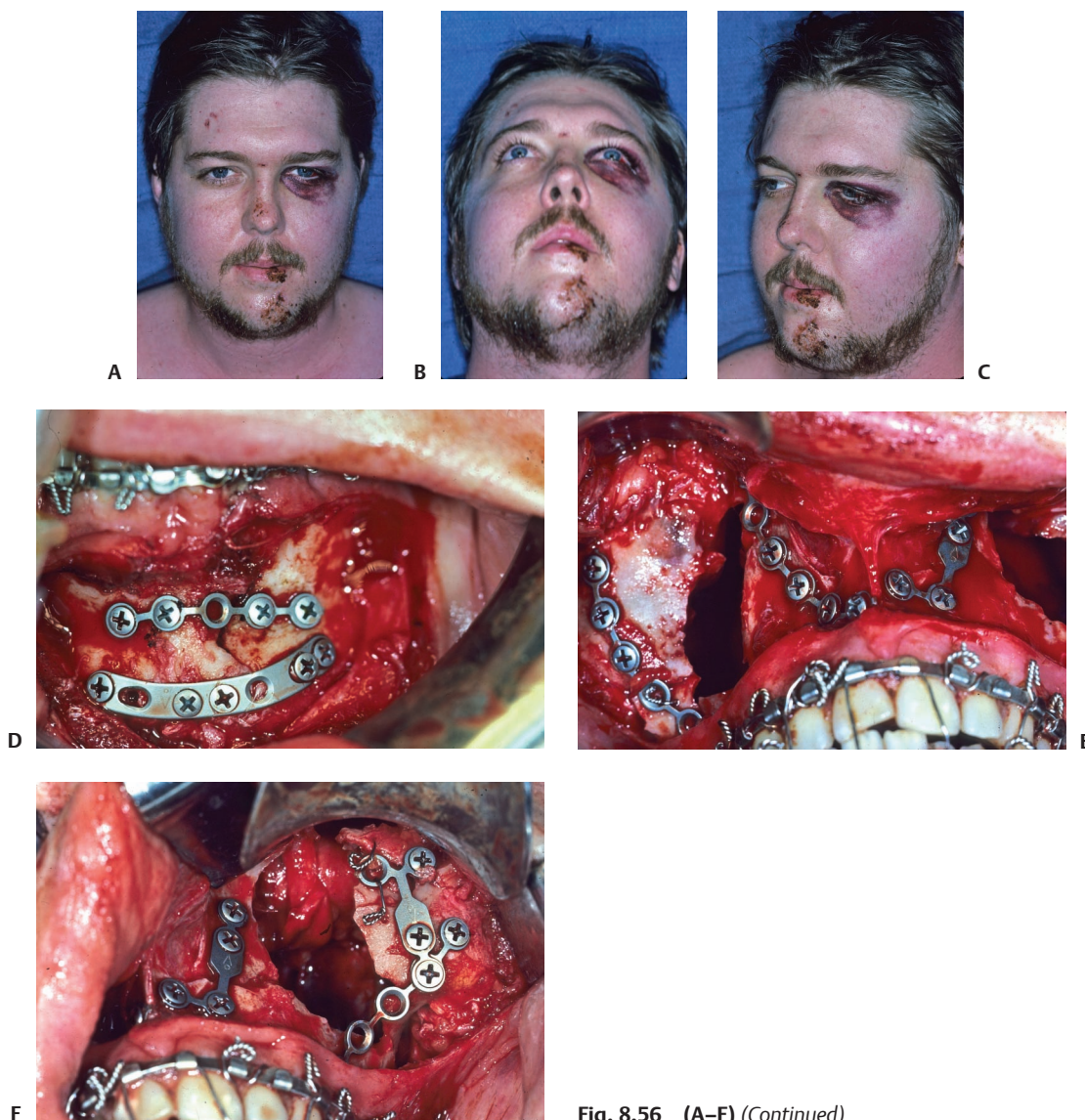


Fig. 8.56 (A–F) (Continued)

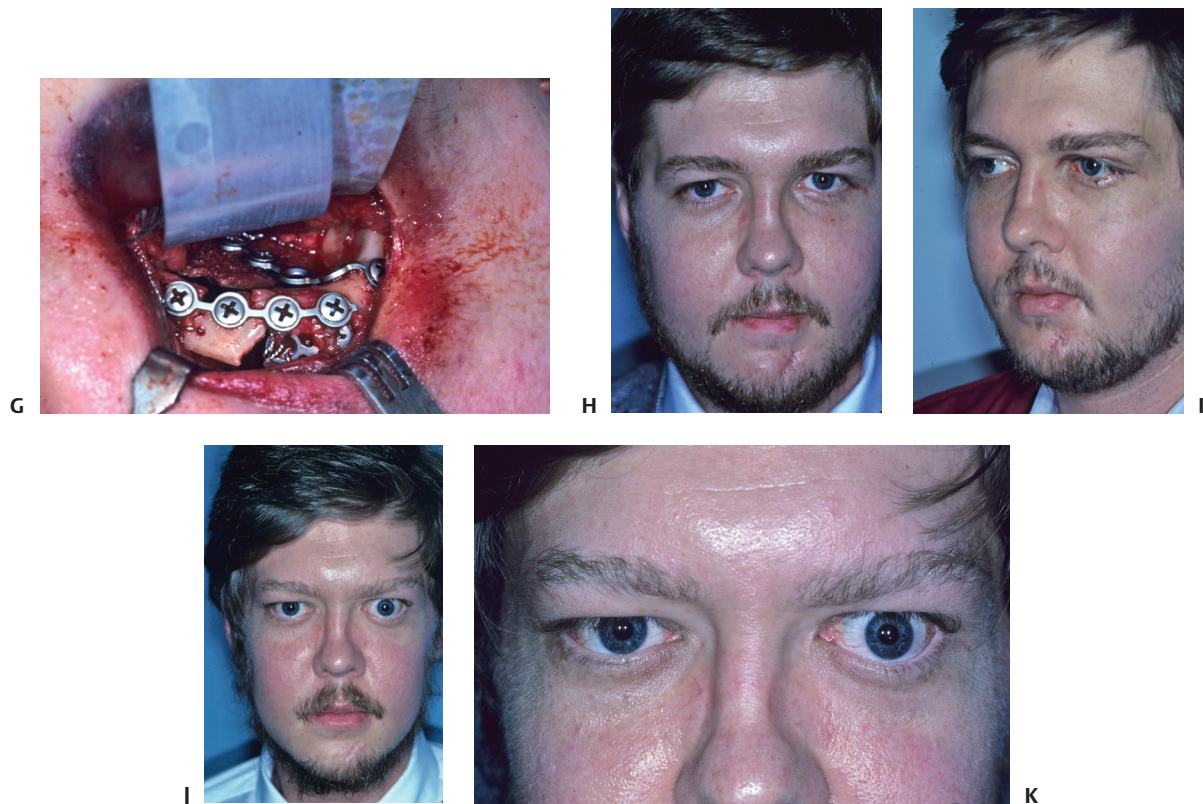


Fig. 8.56 (Continued) (G–K)

■ Key Points

The orbit is created by seven craniofacial bones at the intersection of the cranium and face. Repair of the lateral orbital frame and the orbitozygomatic complex is key to avoiding orbital expansion (enophthalmos) and upper lateral craniofacial bone malalignment, notably inadequate malar projection. Splaying or disruption of the zygomatic arch destroys its role as a “flying buttress,” supporting the greater wing of the sphenoid and malar prominence anteriorly and the temporal bone posteriorly. Commercial implants, such as porous polyethylene, are available for management of many isolated, modestly sized fractures of the orbit. Despite the inherent linearity of the implant, outcomes frequently are excellent. In larger defects, the linearity of the implant is best countered in my experience by manually manipulating the implant to mimic the subtle contours of the orbit, particularly the bilge of anterior and posterior orbital floor, the bilge of the orbital roof, and the ethmoid jut of the medial wall. Contiguous defects of the lower medial wall and medial floor are often corrected by a single graft or implant. At some time in the future, pre-contoured implants, manufactured to match the contours of these and other regions of the orbit, may become available and require minimal to no adjustment. Until then, split cranial bone remains the gold standard for repair of

large, complex areas of orbital disruption. Both contributors to this chapter favor a “transconjunctival gateway” to lower orbital trauma, with placement of the incision in the *lower* fornix. In cases requiring greater exposure, a lateral canthotomy is first achieved. The better outcomes with the combined canthofornix approach can be attributed to bypassing (and protection of) the anterior lamella of the lower eyelid. Upper fornix and particularly subtarsal incisions, by comparison, are avoided for fear of postoperative eyelid malposition. Upper medial orbital wall trauma may require an additional coronal incision, for full exposure of fractures of the *upper* medial posterior orbit.

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9 Pancraniomaxillofacial Injury

■ Part 1. Surgical Anatomy and General Considerations

The 22 bones of the craniofacial skeleton are remarkably resilient and able to tolerate and instantly distribute a wide range of load forces (*facial force equilibrium circuits*) during normal function and after untoward impact (see Chapter 2). As isolated structures yield, fractures limited in scope and clinical measure are manifest. As even greater thresholds are breached, however, the injury takes on disarray, as organized buttresses and platforms are put asunder into an osseous paradigm of derangement and dislocation.

The frontal, ethmoid, lacrimal, sphenoid, and temporal bones form a major aggregate at the intersection of the mid-facial skeleton and the cranium (see Chapter 6). Involvement

of this complex and the adjacent bone establishes the pattern of pancraniofacial injury. Combined injuries of the cranium and face may be limited to the craniomalar, nasomaxillary, and orbitoethmoid regions, or more likely extend to the lower midface and palate or coinvolve the sphenoid, occiput, mandible, or cervical spine.^{1–10} Patients with pancraniofacial injury should be held, for this reason, in the charest regard.

The pancranioface assumes a distorted reconfiguration, typically splayed, broadened, and flattened (lacking projection). The buttresses and microbuttresses of dependent cavities (cranium, orbits, sinuses, nasal vaults, pterygo-palatine fossae, and oral cavity) reflect the alteration of three-dimensional form and the altered cavities settle into a new, deranged architecture with altered volumes.

The extent of injury of the pancraniofacial injury may be broadly cast, as depicted, with a myriad of variation from side-to-side and level-to-level (**Fig. 9.1**).

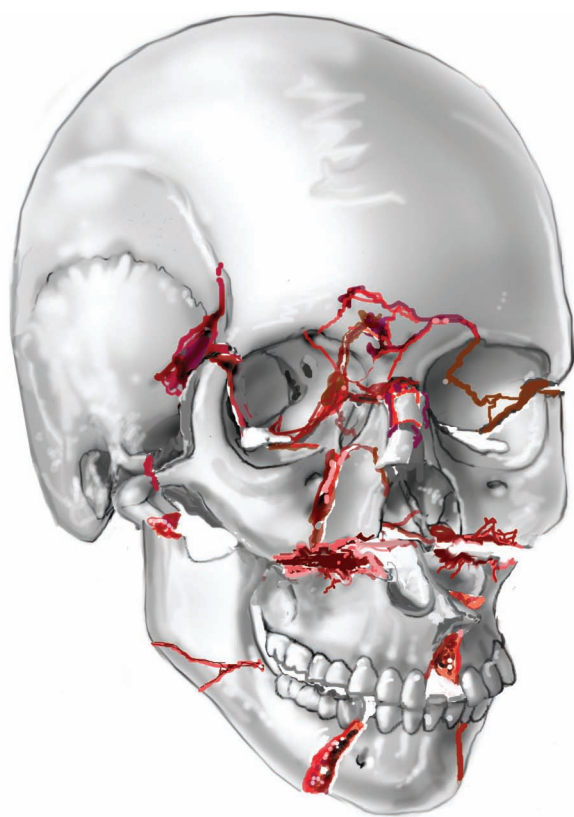


Fig. 9.1

■ Part 2. Operative Technique and Exemplary Repair

Following World War II and during the ensuing decades, surgical repair of combined injuries of the cranium and face was primarily (and sometimes singularly) directed toward the management of the central nervous system. Hematoma was evacuated, compromised brain and necrotic bone were débrided, dural rents were repaired, and depressed cranial bone was elevated as part of the algorithm of the day.^{9,11–15}

Management of facial fractures in days past called for *limited* elevation of periosteum for fear of compromising the viability of the underlying bone. Orts, particularly fragments of the anterior table of the frontal sinus, were frequently discarded (see Chapter 3).¹⁶ In similar fashion, comminutions of the maxillary alveolar process were deemed unsalvageable and summarily shed as problematic waste. Reconstruction of the craniofacial skeleton with acute bone grafting was seldom routinely considered. Halos, suspension wires, trays, oral splints, interosseous wires, transpalatal wires or bars, arch bars, and other adjuncts only partially harnessed the inherent instability of complex craniofacial segments, particularly those of the palate, and several patients experienced postoperative malocclusion and chronically altered dimensions of craniofacial form.¹⁵

Secondary repair was common months or years after injury, aided by the use of so-called foreign substances, such as methyl methacrylate. Great efforts were expended in secondary centers to restore a modicum of form and function, with secondary, even tertiary, procedures or prosthetics.

Preoperative Assessment and Indications for Repair

Clinical Presentation

Airway compromise in patients with pancraniofacial injuries is common, hemorrhage can be profound,¹⁷ and cerebrospinal fluid leak (rhinorrhea and otorrhea) should be suspected.^{18–20} The distortion of the craniomaxillofacial skeleton is hidden by profound edema and ecchymosis of the facial mask in the acute setting, belied by extreme instability of bone fragments. Mobility at several fracture sites, detected by bimanual examination, is, thus, a major clinical clue to the presence of a pancraniofacial injury.⁹

Lacerations, particularly over the glabella (central frontal boss), may communicate through frontal sinus and dura directly into the cranial cavity (see Chapter 6). Drainage of clear fluid through upper and/or midfacial lacerations is deemed to be cerebrospinal fluid until proven otherwise. Airway patency often requires intubation and tracheotomy.

As swelling abates, the extent of injury becomes more apparent. The pancranio-maxillofacial architecture is unmistakably flattened and widened. Nasal projection is lost, and the nasal pyramid tends to tilt upward, accompanied by palpable collapse of the mid and upper struts of the nose and nasoseptum.^{21,22} Comminuted fragments of the medial orbital frame are free to assume a more vertical position, and the medial canthal tendon (whether attached or avulsed from bone) may slip laterally, creating telecanthus. The malar region is flattened as the body of the zygoma is displaced posteriorly, inferiorly, and either outwardly or medially; the zygomatic arch is splayed. The volume of the orbit in one instance is constricted alarmingly in one instance (exophthalmos) and expanded in the other, causing enophthalmos.

Palatal shelves splay outwardly when fractured, creating buccal version of the maxillary dentition (see Chapter 4). The mandible fractured at the symphysis tends to splay at the mandibular angles, and there is lingual version of the alveolar bone of the anterior segment (see Chapter 5). Subcondylar fractures, if present, foreshorten the posterior segment, adding to the loss of vertical height of the face and creating premature posterior molar contact. Instability may be profound.

Radiographic Assessment

High-resolution computed tomography (HRCT) offers great detail and is able to disclose what might be occult fractures after routine radiography. Bands of comminution

and the creation of small orts of bone in select areas suggest the need for bone grafting at surgery. Careful study of HRCT and three-dimensional reformats (and in the case of fractures of the symphysis of the mandible, cone beam computed tomography) facilitates early diagnosis and favors detailed treatment planning.

Force directed over the central upper face creates a radiographic pattern of *central pancranio-maxillofacial fracture*.⁵ The fracture lines typically involve the nasal-nasoseptal plane, the nasomaxillary buttresses, and perhaps, the anterior table of the frontal sinus, and if so, then extend to the medial floor of the frontal sinus and the frontal sinus outflow tract (FSOFT). The medial orbital frame is often displaced medially and inwardly in central panfacial injury, disrupting the orbitoethmoid and even the orbito-sphenoid buttresses (see Chapter 7). The microbuttresses of the orbit are disrupted, apparent radiographically as shattering the medial wall. The orbital apex may be involved, particularly in nonsurviving cohorts.

If the frontal sinus is large, the thick anterior table may absorb a large proportion of the load force, such that the floor and posterior table are spared. If the sinus is small, however, there is a tendency to involve the floor *and* posterior table. If the frontal sinus is rudimentary or fractures occur outside the sinus, large linear or segmental fractures typically traverse the nearby superior orbital rim and medial orbital roof^{7,9,23,24} (**Fig. 9.2**).

Fracture lines may pass through the cribriform plate and roof of the sphenoid sinus, thus becoming basilar.

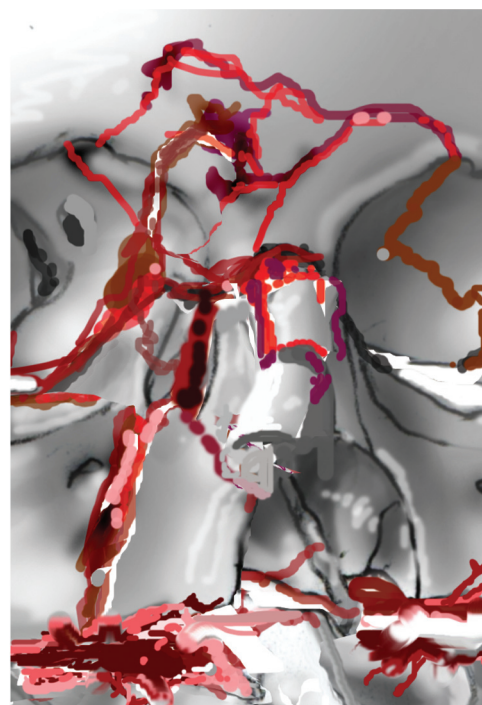


Fig. 9.2

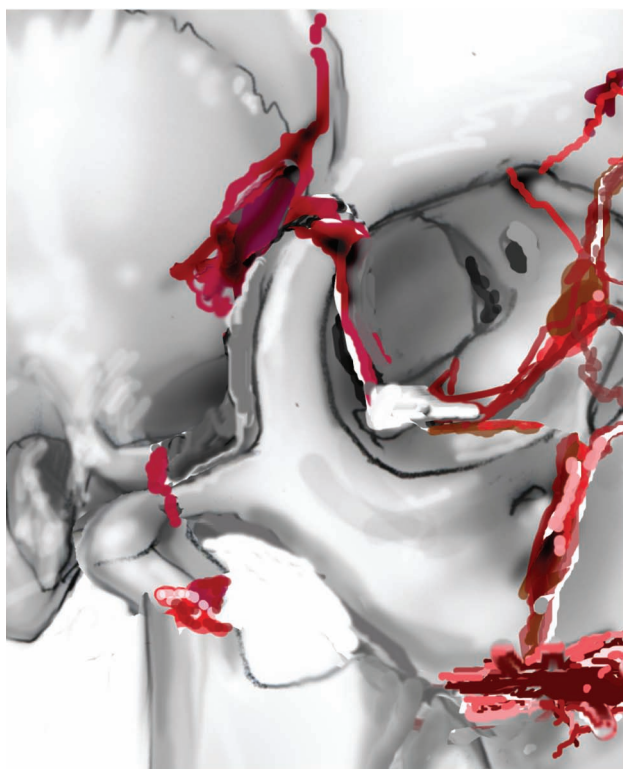


Fig. 9.3

Although these fractures tend to terminate in one of the several foramina in the greater wing of the sphenoid (see Chapter 6), fractures of the petrous ridge may be evident on HRCT, creating a temporobasilar fault.

Force applied in the area of the frontozygomatic suture initiates a radiographic pattern of *lateral* pancraniomaxillofacial fracture.⁵ The frontozygomatic suture may separate widely as the fault descends to divide the orbital plate of the zygoma and the greater wing of the sphenoid, disrupting the normal continuity of the lateral wall of the orbit²⁵ (see Chapter 8) (**Fig. 9.3**).

An ipsilateral Le Fort III pattern is often present, accompanied by a contralateral Le Fort II fracture and bilateral Le Fort fractures, identifiable as broad bands of comminution (see Chapter 4). Fractures of both processes of the zygomatic arch occur. Fractures of this type thus commonly involve the greater wing of the sphenoid and the lateral frontal sinus. The optic nerve is put at risk. In some cases, the outer reach of injury extends to the squama of the temporal or parietal bones (see Chapter 6).^{7,9}

The lateral supraorbital margin is frequently damaged in lateral pancraniofacial fractures,²⁶ and the fault may engage the lateral floor of the frontal sinus and perhaps the posterior table. The FSOFT may be spared injury in these more lateral craniofacial cases because the FSOFT

descends from the *medial* posterior floor of the frontal sinus (see Chapter 6).

The lateral orbital wall and the lateral orbital floor, when outwardly and downwardly displaced, cause an expanded orbital volume, enophthalmos, and orbital dystopia⁹ (see Chapter 8). If the orbital plate of the zygoma is comminuted or the gap at the join with the greater wing of the sphenoid is large, orbital fat may herniate into the temporal fossa.

Combined central and lateral pancraniomaxillofacial fractures involve the central and lateral skull and panface after extreme load forces are applied. Instability is profound. These injuries have a higher probability of extension into the anterior, middle, or rarely posterior fossa; some 20% have associated temporal or temporobasilar bone fractures, and approximately 25% have basilarisphenoid injury.^{5,7,9,24,27}

HRCT may also reveal fractures of the palate with splaying of the palatal shelves (see Chapter 4)^{28–32} and fractures of the mandible (see Chapter 5).³³

Operative Repair of Pancraniomaxillofacial Fractures

Patients with pancraniomaxillofacial injuries require attentive airway management, and controlled tracheostomy (after guide-wire intubation) is commonly undertaken. Neurosurgical procedures are first accomplished and then, at the same setting, craniofacial and maxillofacial restoration is achieved.

Less injured areas are reduced first, and repair of more complex regions follows. Prealignment of fragments is commonly chosen as a prerequisite to applying plates and screws. Management is often tailored side-to-side and level-to-level as the surgeon adjusts to the vagaries of individual injury.

The introduction of plate-and-screw fixation has profoundly influenced the sequence of pancraniofacial fracture management by providing greater control of wholesale instability,^{8,10,34} and various philosophies have been espoused, championing one or more *preferred orders of treatment*, such that the repair is consummated:

- From “bottom to top” (mandible, upper face, and midface)³⁵
- From “top to bottom” (frontal boss, upper face, midface, and mandible)
- “Outside-in” (lateral orbital frame [zygomatic arch and zygoma], frontal bar and medial orbital frame, orbitoethmoid complex, palate, and mandible)⁸
- “Inside-out” (palate, mandible, nasal-nasoethmoid, medial orbital frame, lateral orbital frame)^{36,37}

Clark, in 2000, and numerous predecessors picture the craniofacial skeleton as having a lower “occlusal” half and

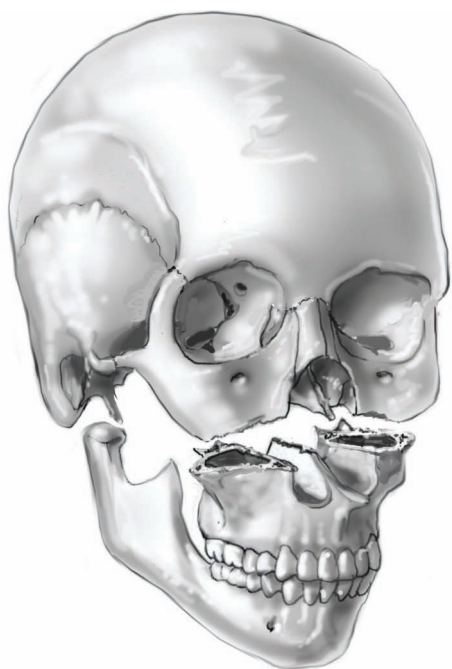


Fig. 9.4

an upper “structural” half for purposes of surgical intervention³⁸ (**Fig. 9.4**).

The feasibility of this conceptualization has been enhanced by the successful outcomes that have followed use of locking plates and screws for repair of the fractured palate and mandible^{32,39} (see Chapters 3, 4, and 5). Like the building of a sanctuary (see Chapter 1), the rigid maxillomandibular block is then able to act as a platform for reconstruction of subsequent suprastructure.³⁴ The lower facial width, depth, and height and the occlusion are the first in pancraniofacial restoration to be declared when this sequence is chosen.

For purposes of treating most pancraniofacial injury, the author pictures the craniofacial skeleton as having three segments, rather than “halves”: lower facial, cranial, and upper facial. The *lower facial segment* consists of the palate, mandible, and the lower aspect of the anterior maxillary buttresses as they are launched from the maxillary alveolus. The *anterior cranial segment* consists of the aggregate created by the frontal, sphenoid, temporal, lacrimal, and ethmoid bones. The *upper facial segment* consists of the central upper face, the lateral upper face, the nasal-nasoseptal complex, and upper portions of the maxilla (**Fig. 9.5**).

The order of management varies according to patient need once operative intervention is under way. Nevertheless, the algorithm in **Fig. 9.6** has been effective in patients with pancraniofacial injury, such that locking plates and screws are first used to control wayward palatal shelves and mandibular fragments.

Incisions and Prealignment

Coronal, gingivobuccal sulcus, lateral canthofornix, and upper neck⁴⁰ incisions usually afford excellent regional exposure (see Chapter 3). Wide periosteal dissection with sharp Molt #9 elevators lifts the periosteum and soft-tissue mask from the underlying bone, permitting effective débridement, irrigation, and buttress reconstruction.

The bias of certain fractures is best countered by prealignment before stable fixation devices are applied. A ratchet forceps, for example, counters splaying of fractured palatal shelves before locking plates and screws are applied³² (see Chapter 4). The tendency of fractures of the symphysis or parasymphysis to gap and the outward rotation or “flare” of the angles of the lower jaw are countered by external pressure at the angles of the mandible with the help of an operative assistant (see Chapter 5).^{10,33} Prealignment of the lateral orbital wall and external pressure along the zygomatic arch, in a similar manner, counters the tendency of the zygomatic arch to splay and lose its normal linearity.⁹ Prealignment in the presence of pancraniofacial fractures has great value as one progresses in the reconstruction from stable to unstable (**Fig. 9.7**).

Twenty-five-gauge wires are chosen for prealignment of bone fragments, though 24-gauge wire may have greater utility at the frontozygomatic suture. Use of a Corwin wire twister tends to avoid mechanical bias within the twisted wire.

Small plates may substitute for prealignment wire and may more conveniently facilitate adjustments in bone position before application of more rigid fixation. Contoured



Fig. 9.5

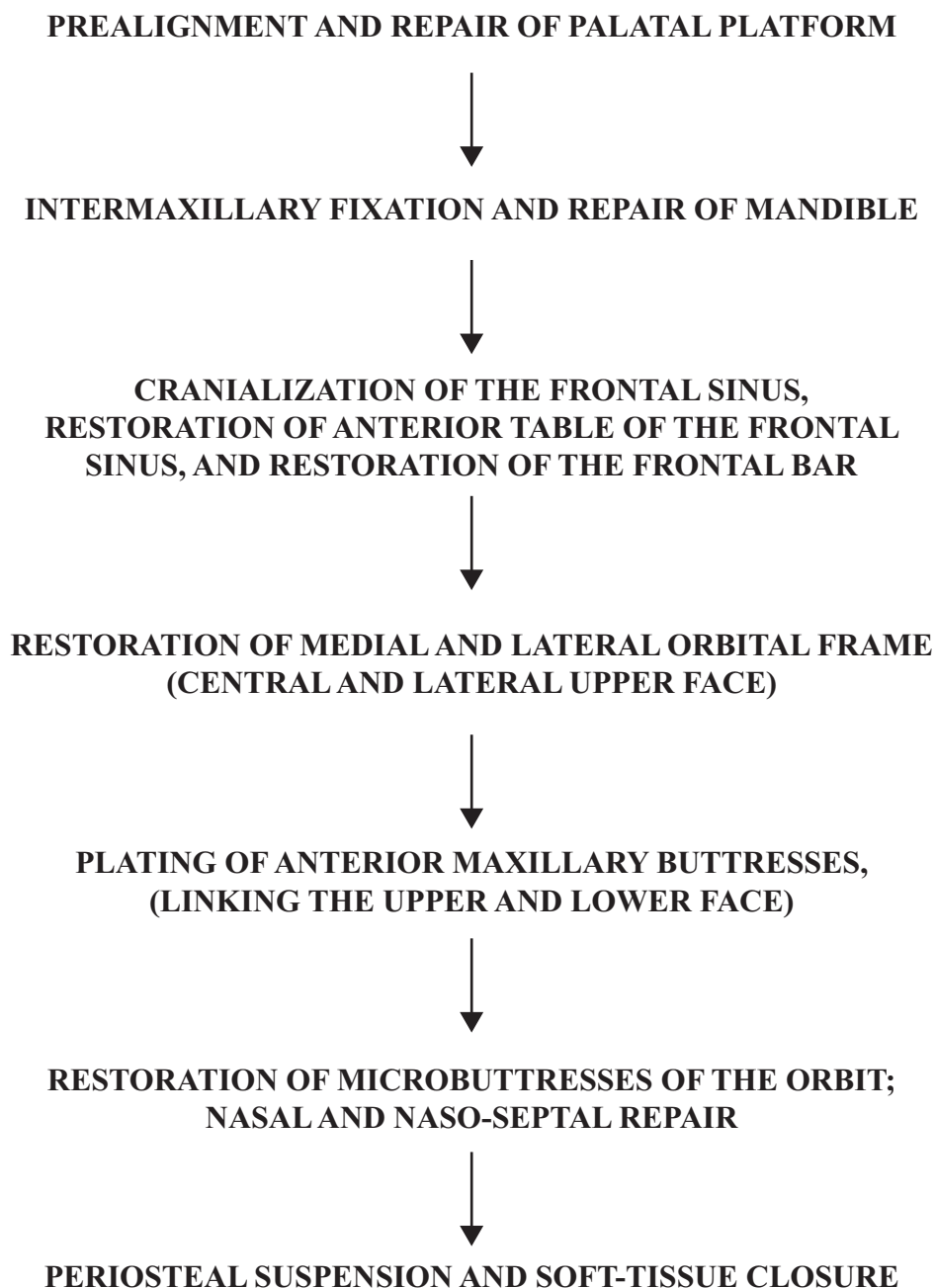


Fig. 9.6

plates are typically applied across the nasofrontal suture to resuspend the nasal bones, and prealignment with wire at this location is waived. If the medial canthal tendons have been avulsed from the medial orbital frame, they are reattached to bone with separate transnasal wires placed *before* nasomaxillary reduction^{37,38,41} (see Chapter 7).

Rigid Stabilization

In a typical sequence, restoration begins with repair of the palatal shelves. Intermaxillary fixation and repair of

the mandible follow. This order of management restores the palatomandibular block as the initial procedure. Incision in, and elevation of, the palatal mucoperiosteum are avoided; the screws are passed directly through the mucoperiosteum into the palatal shelves. A 2.0-mm *mini-locking* system is favored³² (see Chapter 4).

Attention is then directed to cranialization and reconstruction of the anterior table of the frontal sinus (see Chapter 6). Orbitoethmoid (grafts of the medial orbital wall) and nasomaxillary repair then ensue with liberal use of 24-gauge transnasal wires and prealignment of

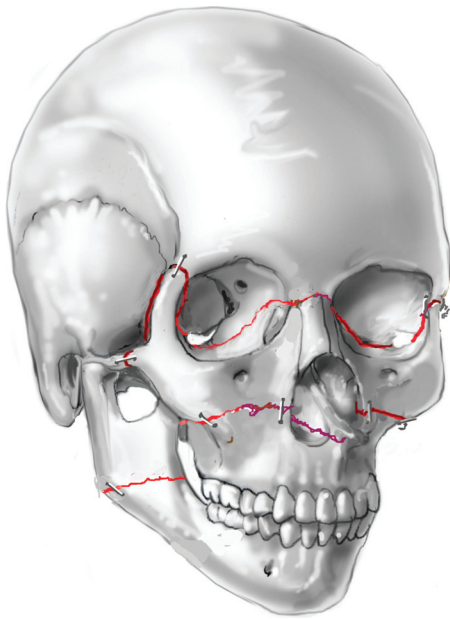


Fig. 9.7

the medial orbital frame with fine, 25-gauge interosseous wires or small plates and screws (see Chapter 7).

Plates applied to the medial anterior maxillary (fronto-nasomaxillary) buttress through the gingivobuccal sulcus may be carried upward across the nasofrontal suture.

Fractures of the zygomatic arch, frontozygomatic suture, and lateral craniofacial buttress are then reduced, prealigned with wire, and stabilized with plates and screws; fixation with 2.0-mm hardware is preferred at the frontozygomatic suture, 1.5-mm hardware fixation at the zygomatic arch and beneath the malar prominence, and 1.3-mm plates and screws across the inferior orbital rim after comminuted injury. Realignment of the orbital plate of the zygoma with the greater wing of the sphenoid restores the lateral orbital wall buttress and its indirect contribution to orbital volume (see Chapter 8).

Reestablishment of the anatomical position of the medial orbital frame is essential for inward reduction and stabilization of the “outer frame” before repair of the orbit (see Chapter 8). Upper facial width, projection, and height are thereby anatomically restored (**Fig. 9.8**).

The author prefers split cranial bone grafts for repair of the anterior maxillary buttresses (1.0-cm gaps and larger). Orbital fractures may be profound, and multiple areas may be involved. Reshapeable commercial implants may suffice, for example, when fractures of the orbital bilge extend to the lower medial wall and may be managed with a single implant. In other instances, multiple bone grafts are best used after consideration of the natural anatomical contours of the orbit; this is particularly true in the complex fractures of pancraniofacial injury.^{42,43} The grafts seem to have greater ease of use, for example, when multiple walls are involved and/or the blow-out fractures are large. The thickness of

the cranial grafts is greater than that offered by commercial products and appears to contribute to restoration of intraorbital volume in our non-blinded evaluation of extreme pancraniofacial injuries over 25 years (see Chapter 8).

Reattachment of the soft-tissue mask (to the reassembled craniofacial skeleton) is a key end-maneuver. Generally, this is achieved by first repairing the periosteum^{10,33,44} (see Chapter 3); periosteal suspension is a critical adjunct in pancraniofacial injury because of the added insult to soft tissue⁴⁵ (**Fig. 9.9**).

Approach to Collateral Damage

Closed Head Injuries

Approximately half of patients with high-velocity craniofacial fractures have concomitant, closed head injuries, some with life-threatening cerebral injury.⁴⁶ Retrospective risk analysis of 4000 patients suggests three global variables warrant a relatively poor prognosis (see Chapter 6):

- Severe neurologic injury, defined by an inadequate Glasgow Coma Score
- Fractures involving the upper third of the face
- Intracranial hemorrhage or a shift of midline, intracranial structures

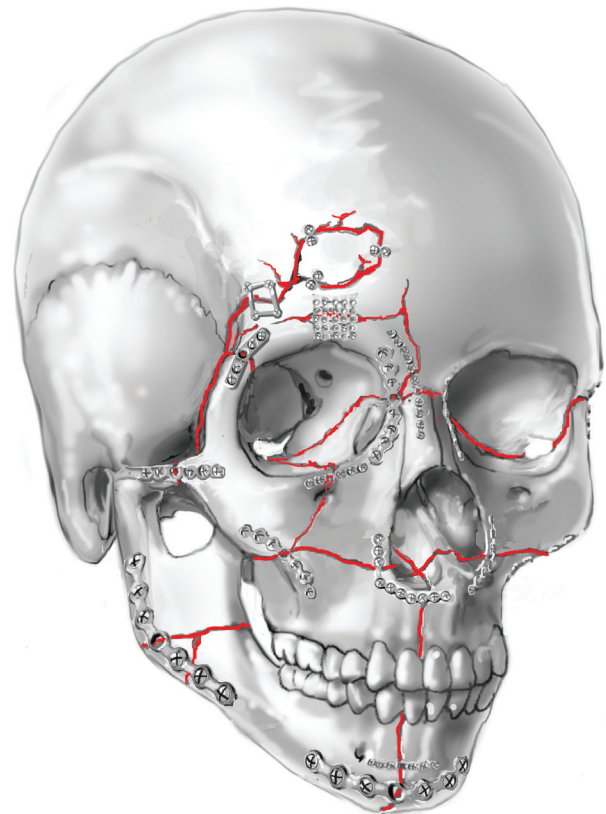


Fig. 9.8

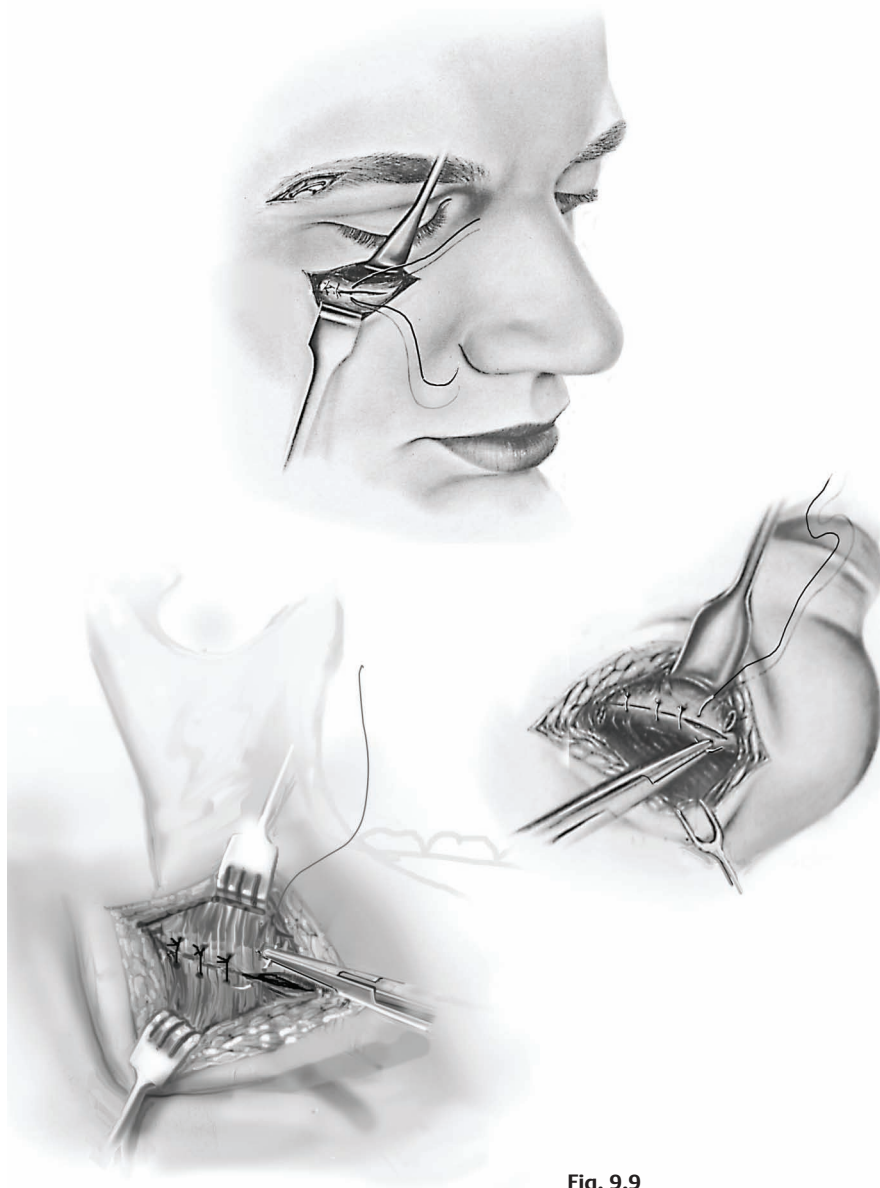


Fig. 9.9

Although several, early clinical constructs (including those by Kaufman and colleagues⁴⁷ and Luce⁴⁸) suggest a higher rate of complication in patients with coexisting neurological injury and craniofacial fractures, follow-on studies indicate no identifiable, significant statistical correlation.²⁴ Other investigations by contrast suggest an increase in complications as the complexity of craniofacial injury escalates.⁴⁹

Combining maxillary and zygoma fractures into one statistical cohort demonstrates that patients with midfacial fractures have *more than twice* the chance of sustaining cranial fractures than patients with mandibular fractures.²⁴ This finding tends to refute suggestions that the midface acts as a biomechanical “cushion” to absorb impact and thus to protect

intracranial content.⁵⁰ To the contrary, statistics support the hypothesis that *facial force equilibrium circuits* are routinely and directly transmitted *to and from* the cranium (see Chapter 2), and the author speculates, to the microbuttresses of the apex of the orbit, the posterior skull base (occiput), and the vertebrae of the upper cervical spine.

External Laryngeal Trauma

Acute blunt trauma to the larynx is increasingly suspected and recognized in the initial evaluation of patients with pancraniofacial injury.^{51–54} Hoarseness, dyspnea, dysphagia, pain on swallowing (odynophagia), dysphonia,

pain with phonation, and other symptoms on presentation merit laryngeal endoscopic examination. Signs of laryngotracheal trauma including hemoptysis, stridor, loss of thyroid cartilage prominence, anterior cervical edema, paralaryngeal ecchymosis, crepitance, palpable fractures, and subcutaneous emphysema are common, according to Butler and coauthors.⁵³

Transnasal endoscopy, HRCT, and magnetic resonance imaging have their place in determining the extent of injury. Cervical spine and esophageal injury (perforation) should be considered.

Cases with external laryngeal and paralaryngeal injury merit close observation and supportive care.⁵⁴ Choices in surgical management, including the benefits and risk of stenting and reduction using 25-gauge wire,^{52,55} await multicenter meta-analysis, to ferret out more structured clinical classification and choices in management.

In one recent study,⁵⁴ approximately one in three patients underwent controlled tracheostomy after intubation at the scene of injury. Functional speech and normal deglutition follow decanulation in a vast majority of cases,

even though hospital stay is lengthened in the cohort of patients with laryngotracheal injury.⁵³

Blunt Injury of the Carotid Artery

Blunt injury to the carotid artery may coexist with craniomaxillofacial trauma and may be immediate or delayed in onset. Serial screening of patients for ischemic symptoms and signs of distal embolization may lead to computed tomography-based angiography and endovascular placement and temporary anticoagulation therapy.^{56,57}

Cervical Spine Injuries

Involvement of the cervical spine in patients with pancraniofacial injuries is a high possibility, as suggested in surviving patient groups and notably the nonsurviving cohort. This issue has been discussed in Chapters 2 and 5. The suspected distribution of *facial force equilibrium circuits* to and from the spine is depicted in the ensuing art (Fig. 9.10).

Exemplary Repair

Case 21. Fractures of the Mandible, Orbitozygomatic Complex, Maxillary, and Orbit

This patient survived an airplane crash but suffered multiple fractures and soft-tissue injuries (Fig. 9.11A–C).

Note the premature posterior molar contact causing an open anterior bite on HRCT (Fig. 9.11D).

The palate was intact. Repair began therefore with the mandible, then the orbital frame and zygoma, orbits, and nose.

“Contour up” and “contour down” split cranial (“top-hat”) bone grafts were placed in the posterior and anterior floor of the orbits after identifying the infraorbital nerve (Fig. 9.11E,F). The grafts were “snapped”/wedged into position without rim fixation. Additional split “contour in” grafts were used to reconstitute the posterior medial wall (not shown).

Nasal and septal fractures were reduced, alar and lateral nasal cartilages were reduced, and lower lateral and upper lateral cartilages were repaired with suture (Fig. 9.11H). The dorsal suspensory ligament and dorsal strut of the septal cartilage were anchored to nasal bone by passing suture through small drill holes in the distal aspect of each nasal bone. Temporary intranasal packing was inserted, and a plaster cast was applied (Fig. 9.11I). A bolster suture and “dental roll” (suture tarsorrhaphy) stabilized the left periorbital soft tissue.

Training elastics and postoperative physiotherapy were effective in realigning bilateral subcondylar fractures.

Follow-up at 1- and 2-year intervals is pictured (Fig. 9.11J).

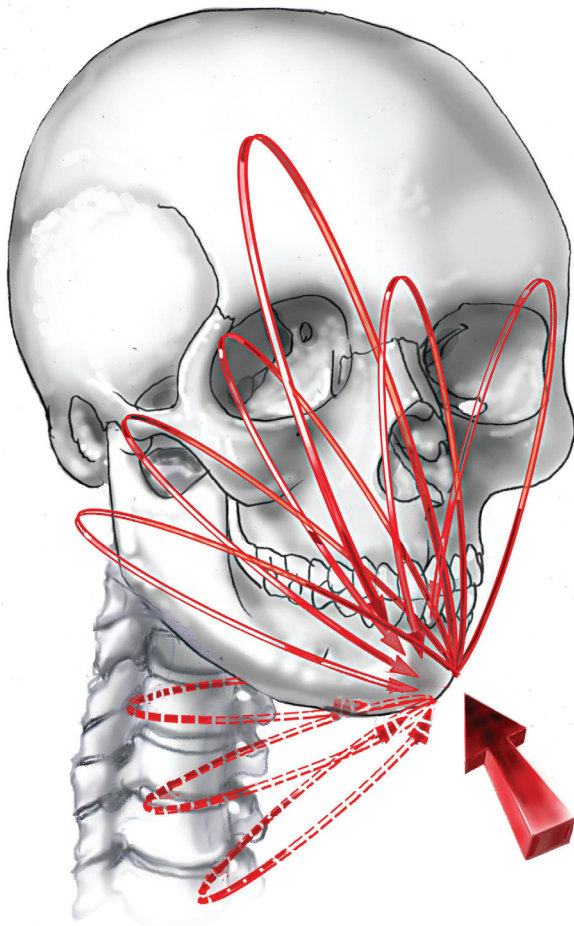


Fig. 9.10

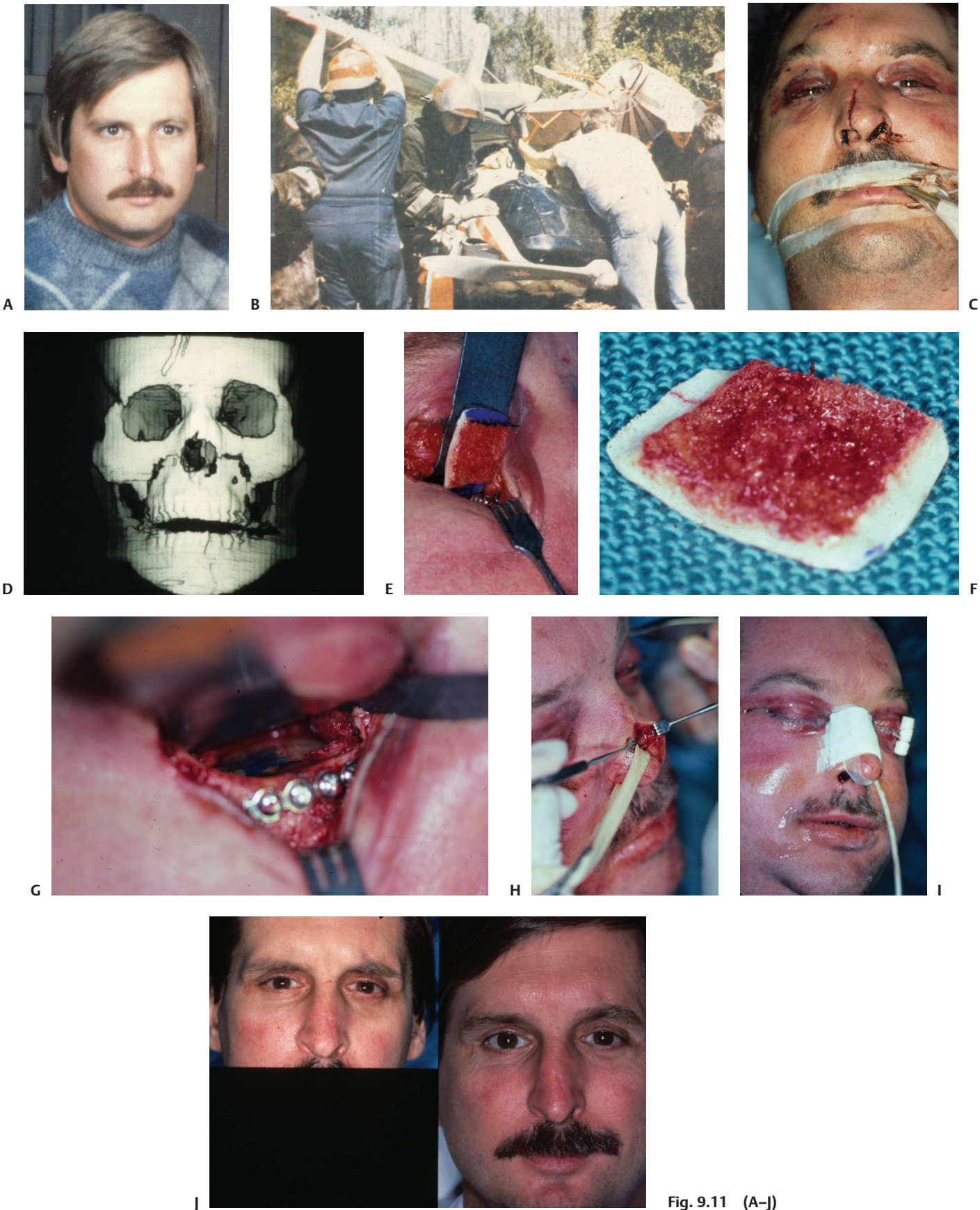


Fig. 9.11 (A-J)

Case 22. Pancraniomaxillofacial Fractures

This young man was involved in a vehicular accident and presented with an open bite and widespread edema and instability (**Fig. 9.12A,B**). The presence of traumatic iritis led to ophthalmologic consultation (**Fig. 9.12C**). Panfacial splaying and flattening of the skeleton presented as a “dish-pan deformity.” The injury included nasal fractures, nasofrontal separation, monoblock nasomaxillary fractures, an orbitoethmoid injury, and bilateral Le Fort I and

II maxillary fractures. The injury extended to each zygoma and comminuted the left zygomatic arch (**Fig. 9.12E,F**). Subtle orbital compression on the right is noted, in contrast to orbital expansion on the left (**Fig. 9.12F**).

Fractures of the symphysis and right angle of the mandible were present, but there was no evidence of a degloving injury of the oral cavity. The palate was spared.

Had fractures of the palate been present, they would have been repaired prior to the repair of the mandible (**Fig. 9.12G,H**). Bicoronal, left canthofornix, gingivobuccal,



Fig. 9.12 (A–L) (Continued)



Fig. 9.12 (Continued) (M-V)

and (Risdon) external incisions afforded broad exposure, to facilitate rigid fixation.

Digital compression triggered collapse of the upper and middle compartments of the nose. Central upper and lower midfacial injuries were accompanied by fractures of the mandible at the symphysis and right angle. Note lingual version of the anterior segment of the right mandible (**Fig. 9.12G**).

Arch bars were applied and the mandibular fractures were manipulated and openly repaired by way of a gingivobuccal incision. Splaying at the angles was countered by inward pressure, and the fracture of the symphysis was reduced and plated.

The fragments of the medial anterior maxillary buttresses and the medial orbital frame were stabilized, and the nose was resuspended from the frontal boss (**Fig. 9.12I**). The comminuted zygomatic arch was repaired, then each zygoma and the left inferior orbital rim (**Fig. 9.12J–L**). In the case of the infraorbital rim, a bone assembly was first created (see Chapter 3) (**Fig. 9.12L**). The remainder of the midface was reconstituted, on the left with split cranial bone (**Fig. 9.12M**).

Blow-out fractures of the left orbital floor were repaired with multiple split cranial bone grafts. The inherent convexity of the grafts was used to mimic the contours of the orbit (**Fig. 9.12N–P**). Beveled at the edges, the grafts “clicked” like mortise into position, requiring minimal rigid fixation. Periosteal suspension and closure of the wounds completed the operation. Drains from the scalp exited in the postauricular area and were placed at bulb suction.

Symmetrical postoperative panfacial projection is depicted postoperatively (**Fig. 9.12Q–S**). Note the restoration of the normal contour of the lower eyelids and lateral canthus, relative to the medial canthus. Pretraumatic occlusion, acceptable interincisal excursion, and prior panfacial proportions have been reestablished (**Fig. 9.12T–V**).

■ Key Points

The pancranio-maxillofacial fracture is the ultimate challenge in craniofacial repair. Comminution, flattening (splaying) and rounding of craniofacial structure, and dislocation and extreme instability are most evident, particularly when pancranio-maxillofacial injury is both central and lateral. Algorithms of repair vary according to clinical need but often begin with the palate, then mandible and upper face. Medial and lateral orbital frame realignment precedes reconstitution of the maxillary buttresses and restoration of the orbit. In some cases, commercial implants are a valuable adjunct, but in cases with severe comminution and displacement, rigid

fixation devices and split-cranial bone grafts afford better aesthetic and functional result. Meticulous periosteal suspension and soft-tissue repair, though end acts, are critical to successful outcomes.

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